ENGINEER'S REPORT

JULIE SPRAFKA INJURY

Julie Sprafka, Plaintiff, v. DePuy Orthopaedics, Inc., an Indiana Corporation and Medical Device Business Services, Inc., an Indiana Corporation.

In the United States District Court, for the District of Minnesota
CASE 0:21-cv-01785-DSD-ECW

By:

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March 3, 2023

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INVESTIGATION OF THE JULIE SPRAFKA INJURY

ENGINEERING REPORT **March 3, 2023**

A. INTRODUCTION

On August 18, 2016, Dr. Andrea M. Saterbak implanted an ATTUNE Knee System in 55-year-old Julia Sprafka's right knee at the Lakeview Hospital, Stillwater, Minnesota. Per the operative records, and the Complaint in this matter, the following specific devices and components were implanted:

1	2	3	4	5
Bone Cement , 2 packages (records state Quickset Mfg by J&J Cordis Webster[A]) Matl: Methylacrylate Copolymer, methylmethacrylate monomer Ref: 3322-020 Lot: 8280491	DePuy Attune Tibial Base Fixed Bearing Size 6 Cemented Matl: CoCr Ref: 1506-00-005 Lot No.: 8318475	DePuy Attune Tibial Insert Fixed Bearing Cruciate Retaining Size 6 5mm AOX Matl: Antioxidant UHMWPe Ref: 1516-20-605 Lot: C42624	DePuy Attune Femoral CR Size 6, 5 mm Right Cemented Matl: CoCr Ref: 1504-00-206 Lot: "N/A" on records	DePuy Attune Patella Medialized Dome Size 38 mm Cemented AOX Matl: Antioxidant UHMWPe Ref: 1518-20-038 Lot: "N/A" on records

The Attune TKA components were designed, manufactured and sold by DePuy Orthopedics, Inc. and/or Medical Devices Business Services, Inc. (DePuy), both Johnson & Johnson (J&J) companies. The hospital records listed the bone cement to have been manufactured by J&J Cordis Webster.

Following her primary surgery, she initially had some swelling and difficulty gaining range of motion. Unfortunately, as tine progressed, her right knee remained painful and stiff in the morning, becoming more painful, stiff with some swelling with increased use (standing, walking). Her pain decreased with rest, ice, passive stretching and, later, and ibuprofen. A bone scan done in November of 2018, 2 ¼ years postop revealed hyperemia about the right knee but no findings specific to right knee loosening. By 4 years post op her right knee was still painful with weightbearing activity, ranging from 3/10 to 7/10 , and was especially when she goes from a seated to standing position especially for the first few steps which Dr Breien noted was fairly classic startup pain. Her pain and associated symptoms(stiffness, weakness and giving way) were worsening. She reported more pain over the tibia than the femur. Her physicians documented no signs of infection or persistent swelling. Dr Breien diagnosed a little lucency between the cement mantle and the anterior portion of the tibial stem or tibial keel on lateral x-rays taken on June 10, 2020 and ordered a 3-phase bone scan, which was completed by Joshua C. Zawacki DO on June 23, 2020. The scan revealed increased tracer uptake about the right knee arthroplasty Attune TKA hardware which was concerning for changes of

[A] DePuy CMW 2 Bone Cement was listed, with lot numbers, in the complaint.

osteolysis/hardware loosening. Breien recommended revision of the DePuy first generation Attune total knee, which was performed at Woodwinds Hospital, Woodbury MN on September 15, 2020, about 5 years following her index surgery. The entire device was removed and replaced with DePuy Sigma revision TKA devices. Intraoperatively Dr Breien noted that the tibial component showed slight micro motion at the implant cement interface and separated from the cement mantle with just 1 tap confirming cement interface loosening (debonding). He also noted that the entirety of the cement mantle stayed intact with the tibia, and that there was no remaining cement on the back of the tibial component.

Recuperation from the revision TKA was slower than her primary TKA, however she recovered sufficiently to allow return to work with restrictions at three months post op (11/20/2020). At seven months post revision she was still having some discomfort and some swelling after activity, but was able to negotiate stairs using an alternating pattern. At one year post revision of her right total knee arthroplasty, her medical records indicate that she was doing well, and was walking with a normal gait without pain or swelling. At most she reported occasional pain of 2/10 to her physical therapist, but was mostly pain free.

As a result of the use of the Attune total knee system Julie Sprafka suffered with a painful right knee for five years following her index TKA due to loosening (cement debonding). She suffered another 3 to 6 months as she recovered from the surgery to replace the failed Attune implant. Her full recovery form the revision was documented at one year. She has recurrent but mild residual pain in her right knee.

The purpose of my review was to determine if the Attune Total knee components implanted into Julie Sprafka were defective in a manner to cause the early tibial tray loosening failure (cement debonding) which resulted in her injury including additional knee arthroplasty surgery and the related recovery.

B. CREDENTIALS: QUALIFICATIONS AND EXPERIENCE

Credentials: Qualifications and Experience

This report, in conjunction with materials relied upon during proceedings; include my opinions in the form of findings, and the basis for these opinions. I am offering my opinions to a reasonable engineering and scientific certainty. To the extent that additional discovery is produced, I may alter or formulate additional opinions. **A summary of my findings in this matter can be found on pages 73-75.**

Qualifications

I am a biomedical engineer with 42 years of experience in the biomechanics and orthopedics fields. Biomechanics is a sub-specialty field of bioengineering, and orthopaedic biomechanics is a further sub-specialty, which involves the application of principles of engineering mechanics to understand basic biological processes and mechanisms related to the structure and function of bone and other skeletal tissues, while the broader bioengineering field does the same relative to the structure and function of all living tissues. Orthopedic designers compile and use property databases of bone and other tissues. As a result, I routinely deal with forces that are applied to

the human body during many activities, including impact and injury scenarios. To assure the safety and efficacy of new medical devices, we define clinically relevant performance requirements for their installation and use, and then test to define the product specific performance characteristics, as well as how that clinically relevant performance is communicated to surgeons in labeling, marketing, written communications, and medical education presentations. The physical principles and methods used in orthopedic biomechanics are the same as those used to reconstruct injury events. I am familiar with forces and loads applied to the hips, knees, wrist, shoulder, head, neck, lower back and skeleton in many typical activities, including sitting, walking, jumping, running climbing, standing, falling, sport, recreational activities, and vehicular collisions. I hold twelve patents for orthopedic devices, and am a member of, among others, the American College of Sports Medicine, the American Society of Mechanical Engineers, the International Society of Biomechanics, the Orthopedic Research Society, North American Spine Society and ASTM International. I have several years of development and design experience in the area of human joint reconstruction, spine and trauma reconstruction, and have been involved with total joint implants since about 1983, and spine and trauma reconstruction devices since 1980. My experience includes designing orthopaedic devices as well as directing, analyzing and performing laboratory evaluation of performance characteristics for orthopedic implant and instrumentation systems.

These evaluations included:

- Impact biomechanics of the thoracic spinal discs.
- Range of motion, fatigue and wear endurance characterization of various total joint implant designs for the knee, hip, wrist, PIP, thumb based CMC joint, and foot MT and DIP joints.
- Stability characteristics of total joint implant devices and reconstructions, including stability under anticipated physiological and some injury load conditions.
- Impact strength and fracture resistance of bone, implants and instruments during surgical reconstruction procedures.
- Implant fixation strength and construct stability characterization for various bone fracture repairs using: external fixation, spinal rods screws and hooks, intramedullary nails, bone screws, cannulated bone screws, plates with screws, and k-wires.
- Ligament reattachment strength and fixation stability in foam bone model material and animal bone.
- Minimally invasive orthopedic surgical procedure instrument construct stability and accuracy.
- Bone cutting efficiency for specific orthopedic surgical cutting tools.

While I was at DePuy, the engineering development staff had design, development and product maintenance duties for product lines in their areas. For me, over time, that included design of spinal and fracture management implant systems as well as extremity joint, knee and hip devices and related instrumentation. Starting in 1980, and periodically since then, I participated in the design of spinal rods, hooks, pedicle screws, cables, plates, cages and spinous process capture device s. The fusion implants included anterior and posterior devices for trauma, deformity correction, and degenerative fusion procedures cervical, lumbar and thoracic spine, single and multi level.

In my work as a designer and/or project manager for hip, knee, ankle, wrist, finger and toe prostheses as well as other spinal, trauma and soft tissue repair devices a significant battery of laboratory bench testing, including fatigue-wear testing in physiologic fluids (arthroplasty devices), and pre-clinical evaluations in animal bone and in human cadavers were completed. I also reviewed product failure complaints for various product families while working for DePuy and again at Zimmer (now Zimmer Biomet), and occasionally as requested by my other orthopaedic manufacturer customers. While at Biomet (now Zimmer Biomet), I designed patient-matched total hip stems. I have worked on several instruments used to align cuts, prepare bone and impact total hip, knee, and shoulder implants, and more recently, I completed projects for three smaller orthopaedic companies in the areas of hip implant acetabular cup, multi-modular hip stem and a more traditional femoral stem design with single head-neck modularity.

For the last 20 years, my company has continued to support R&D projects in trauma, spine, and hip and knee implant systems with design, risk assessment or other performance or stress analyses.

My career began as a designer of orthopaedic implants, however for over 20 years I have also been assessing the forces causing human injury in events including occupant contacts (impacts) during motorized vehicle crashes (impact biomechanics). Automotive injury biomechanics is a sub-set of injury biomechanics and is the study of the mechanism of impact injury to the human body, the mechanical and other physiological responses of the tissues involved, human tolerance to impact and the effectiveness of countermeasures incorporated into vehicles to mitigate injury. Biomechanical engineers perform experimental and analytical studies to quantify the human body's mechanical responses that occur during various loading environments.

More recently, in my work reviewing failed devices associated with litigation I have examined many 'dear doctor' letters sent by manufacturers to surgeons with important medical information (IMI), and/ or recall notification. Depending on content, these letters were typically written by consulting surgeons for the manufacturer, by clinical or regulatory professionals within the organization, or by a medical officer employed by the manufacturer.

Having been a designer, development team member, and more recently a consultant to industry, I have actively participated in both the creation and review of warnings and precautions provided in package inserts and surgical techniques for well over a dozen orthopaedic product families for about a dozen different orthopaedic companies. If a hazard and resulting harm cannot be designed out of a product, the second line of action is an adequate warning and communication of those risks in written communications, marketing, and medical education presentations. This is a basic design tenet first learned and applied in the classroom, and then carried out in practice over my 41 years as an engineer in the orthopaedic industry. Beginning in about 1990, as a normal part of development, I routinely complete failure modes and effects analyses (FMEA), risk analyses with risk estimates, identify, and apply methods to reduce risk of hazards and harm. This work is done in conjunction with the development team, which generally includes other engineers, marketing, quality representatives and a surgeon or medical reviewer in addition to management reviewers. The warnings that are provided in package inserts for new products are reviewed by the design teams. In my career, I have been a member of such teams numerous times. Through both

experience and training in reviewing, writing, and discussing warnings with team members and with orthopaedic surgeons I am qualified to comment on the adequacy of the information contained in the manufacturer's instructions for use (IFUs),promotional materials, surgical techniques, written communications, and medical education presentations, from the perspective of an orthopaedic system designer in the medical device industry.

My marketing experience included communications with the field, sales training and coordinating medical education related to knee products, another type of orthopedic implant used by surgeons. At DePuy in the 1980s, R&D and marketing teams worked together on new product development, as well as surgeon education and sales training concerning implant technology and customer support. The sales force was encouraged to call the team with technical questions and we were accessible to discuss/resolve /report adverse events. As a product manager, I spoke with and interfaced with sales representatives and distributors throughout most business days, and with our surgeon-designers and other surgeon users on a weekly basis.

A copy of my curriculum vitae is also attached, and includes my work experience, professional affiliations and publication list.

Methodology

As a biomechanical engineer with experience in orthopedic device design, implant fixation, material damage (wear/fatigue/creep), I take an evidenced-based approach to the performance of my work in the ordinary course of my practice. I have applied those principles here in my review and critique of the DePuy Attune TKA failure (tibial baseplate cement debonding) from the perspective of a scientist with experience in medical device design, development and marketing.

The first step in the evaluation of a medical device forensic matter is to request and review the patient's medical records, explanted devices (when available) and, when made available, the manufacturer's internal documents concerning the design, manufacturing, regulatory, marketing, labeling and other and communications documents[B] that reflect on the conduct of the company and the industry. In addition, I review depositions and the scientific literature to ensure that I am familiar with the medical history of the product, and I compare that information with what was being discussed within the company. Finally, I rely on my background, training and experience, including my experience as a forensic expert, to evaluate whether the device(s) at issue are unreasonably dangerous and defective in a manner that caused or contributed to the failure and the patient's diagnosed injuries.

In reaching my conclusions and opinions, I have had access to selected documents from a database of documents electronically produced by defense for this litigation and have reviewed documents from that database. A list of documents I considered and relied upon for my opinions in this report are set forth in Appendix A as well as the references cited within this report.

[B] To included communications with surgeons, hospitals, salesforce, Joint Registries, the FDA, and other regulatory bodies.

I reserve the right to amend this expert report when additional fact discovery becomes available, such as the deposition of treating physicians, sales representatives, and other fact witnesses and/or discovery materials from DePuy for the Attune. It is my understanding that the following have been requested: Device history records for the products implanted in Ms Sprafka, updated risk analyses, CAPA files, Health Hazard Evaluations (HHEs), updated complaint trending, updated post market surveillance files, surgeon or sales force training materials, or 'dear doctor' letters concerning the Attune baseplate, among other things.

In this and other orthopaedic total joint implant cases, I rely on medical doctors, including orthopaedic surgeons and pathologists, for medical causation. Those diagnoses delineated herein are taken by me as fact.

Terms of Compensation

The professional service fee I charge for all tasks that I have undertaken in this case is $340 per hour, subject to change. New rates are effective from the date of change. Rates apply to all work including site inspection, analysis, travel, report writing, depositions and trial. Additional charges may be incurred at standard rates for testing equipment and test services, out-of-pocket costs for travel related expenses and other services used for case preparation.

I have invoiced $18700 for my time and expenses specific to this matter.

Testimony as an Expert

A document (Exhibit 2) listing my testimony record for the previous four years is also attached, and includes 54 total instances (9 at trial). In about 52 of the proceedings, I testified on behalf of the plaintiff counsel, the balance (2) for the defense. These cases involved personal injury litigation.

Exhibits

I may use the materials listed as available information and all items cited, end noted or footnoted in this report and its exhibits and appendices or exhibits, or demonstrative exhibits as exhibits to illustrate testimony.

Concerning this report there are five (5) Appendices (A-E) and four (4) Exhibits:

Appendix A – Materials Considered
Appendix B - Forces on the Implanted Knee
Appendix C – Selected Team Discussion - Tibial Baseplate Finish
Appendix D Background: Tibial Cement Mantle Thickness & Bone-Cement Interface Tensile Strength
Appendix E DePuy's Non-compliance with Federal Code CFR 803 MDR Reporting

Exhibit 1 - Current CV for Mari Truman
Exhibit 2 - Rule 26 Testimony list for Mari Truman
Exhibit 3 - Defense Discovery Response Diabla, Exhibit 2, Table
Exhibit 4 Literature Review - Tibial Component Debonding in TKA

C. DESCRIPTION OF THE INCIDENT

Selected Medical Record Notes

[8/18/2016, Andrea M Saterbak MD, Operative report, Health Partners]

- Pre & postoperative Diagnosis: Osteoarthritis Right Knee
- PROCEDURE: This patient is brought to the operating room, given anesthesia, 2 grams of Ancef IV. A time-out was called and the patient and procedure were verified. A Physician Assistant was required for adequate retraction. After prepping and draping, the tourniquet was elevated. On the right thigh a midline medial parapatellar incision was created approximately 7 centimeters in length. The joint capsule was incised and a mid vastus split was created. We were able to view the entire knee. Findings: DJD. The patella was everted, sized to a 38 mm and then resurfaced and the pegs were drilled. After noting these findings we then placed the intramedullary distal femoral guide and the distal femoral cut was created. This was followed by sizing the femur to a size 6. The anterior, posterior and Chamfer cuts were created. We then exposed the tibia, the residual of the meniscus was removed. The ACL was removed. We then placed the extra medullary tibial guide and this was set to remove 2 millimeters of bone with slight posterior slope. I then sized the tibia to a size 6, this had good cortical coverage and anterior posterior coverage seemed good.
- We then trialed with the above listed components. The rotation was set. I was pleased with the ligament balancing. The patella tracked well. We then irrigated the wound. A Physician Assistant used 3 retractors to expose the knee prior to cement. I then removed all trial components and irrigated the trabecular bone and cemented them in sequence, tibia, femur and placed the poly into the tibial tray with good capture. The patella was cemented in to place. After the cement hardened, the tourniquet was removed. A drain was placed and the knee compound was injected into the medial capsule. The wound was closed in layers with 0, 2-0 vicryl, 3-0 monocryl and Prineo A dressing was placed. The patient was sent to the recovery room in stable condition.

[8/18/2016, Henry K Swica MD, Anesthesia, Health Partners]

- Anesthesia Summary - Sprafka, Julie M (90954709] Female 61 years old
- 5'6" tall , 214 lb, BMI 34.54

[8/19/2016, Cheryl L Oeltjenbruns, PA-C, Twin Cities Orthopaedics Progress Note]

- Objective: Vital signs in last 24 hours
- Her height is 5' 6" (1.676 m) and weight is 97.07 kg (214 lb). Her oral temperature is 98 °F (36.7 °C). Her blood pressure is 118/67 and her pulse is 70. Her respiration is 16 and oxygen saturation is 100%. Her body mass index is 34.56 kg/(m^2).
- Plan:
  1. Continue cares and rehabilitation
  2. Anticoagulation protocol: ASA 325 mg daily x 42 days
  3. Pain medications: Will try switching pain medications to resolve the nausea today
  4. Weight bearing status: WBAT
  5. Disposition: Home Tomorrow if nausea resolves and patient completes therapy

[8/22/2016, Thomas P Nelson, PT, MS]

- Referrer: Andrea M Saterbak MD

- Patient presents after 08/18/2016 right TKA, 4 days post op. Discharged from hospital yesterday. She states she is function going well at home. Patient reports compliance to given exercises. Wound dressing changes go well.
- Observation: Patient presents with single point cane, modest limp. She is offered wheeled walker for home (alone) and night use. Wound healing well, no noted drainage. Minimal/modest swelling. She is instructed in elevation above heart, ankle pumps and toe wiggles. She wears compression leggings, appears motivated and is very pleasant.
- Palpation: Good scar and patellar mobility. Lymph drainage with elevation instruction issued. Surgical tenderness as expected. No calf tenderness or complaint of calf pain.
- Range: R knee flexion to 80 degrees, R knee extension lacks 12 degrees. Patient is issued home gentle flexion and (more) aggressive extension therapy ex/positioning. R hip and ankle within normal functional limits (WFL).
- Strength: All L/E planes intact. Pt is not able to SLR independently, minimal assist and 20 degree lag. Dorsi plantarflexion = WFL. VMO deficit noted with attempted SLR.

[10/4/2016, Elizabeth M Senoraske MPT, River Valley Physical Therapy]
- Subjective: MD happy with progress. Patient will go back to work next week part time. Exercises are going well. Minimal swelling noted. Knee extension AROM to about 2 degrees, PROM 0 degrees. Pain at worst is 5/10 with bending, best 0/10. Good demo of exercises. Tried bridge but a little discomfort laterally on the knee.
- Assessment : Pt. post op right TKA, almost 7 weeks. Doing well. Continue exercises including SLR and seated extension with weight for prolonged time 15 min as tolerated, SL balance for 2 min with breaks, SL abd, clams, bolster for extension, prone curls- 2.5#, reviewed step ups and downs to assist with up I down stairs at home. Did leg press 40#, TRX squats, calf raises, BAPS for balance.
- Plan: Cont POC 1x next week, then in 2 weeks to work on ROM, strength and balance.

[11/1/2016, Elizabeth M Senoraske MPT, River Valley Physical Therapy]
- Subjective: Patient is doing better than last visit. She is now off work again for at most 3 months. She noticed swelling has -decreased as well as -pain. Exercises are going -better now that not in so much pain.

[11/3/2016, Elizabeth M Senoraske MPT, River Valley Physical Therapy]
- Subjective: Patient is is doing well. Did some raking yesterday so some soreness with this, but settled down nicely with elevation and ice. Good -to be able to rest as needed vs. -standing/walking on concrete floor for 4 hours at a time.

[11/7/2016, Elizabeth M Senoraske MPT, River Valley Physical Therapy]
- Subjective: Patient is doing better since she is no longer working. Her exercises are going well and she has been diligent with -them. -KT for-swelling seemed to help. Over the weekend she was less swollen, per patient.
- Objective :Minimal swelling noted- decreased from last. Knee extension AROM to about 4 degrees, PROM 1-2 to 107 degrees. Good demo of exercises.
- Assessment: Pt. post op R TKA about 11 weeks. Pt. did well with treatment including manual therapy and exercises. We did some of the following in the clinic: SLR and seated extension with weight for prolonged time 15 min as tolerated, SL balance for 2 min with breaks, SL abd, clams, bolster for extension, prone curls- 5#, step ups and downs to assist with up /

down stairs at home. Did TRX SL squats with other foot forward for balance, SL calf raises, SAPS for balance. Leg press with 30# done in clinic without issue-20# SL, did drinking bird with TRX. Cont. LAQ with reps to fatigue, squats with ball behind back with riser at home. Reviewed bridge 1 Ox2. Added prone quad stretch with band, which worked well.

- Plan: Cont POC 2x this week, then 1-2x / week ta work-on -deer-easing ·pain and swelling, and increasing -ROM, strength and balance, as well as walking endurance.

[11/10/2016, Elizabeth M Senoraske MPT, River Valley Physical Therapy]

- Subjective: Patient is doing well. She does have soreness when she overworks the knee, such as biking for 20 minutes then -going for a walk. Ice helps with this. Still stiffness after prolonged sitting and swelling -increases at times, usually laterally.

[4/3/2017, Elizabeth M Senoraske MPT, River Valley Physical Therapy]

- Injury Date: about 3 / 3 / 17 - exacerbation of pain
- Surgery Date: Index TKA 8/18/2016
- Pt was finished with PT for her R TKA in December of 2016. She was discharged to her HEP and was doing well. She returns today due to increased pain in the knee in the last month.
- Mechanism of Injury Insidious - pain started, more stiffness and increased swelling noted with increased work hours and following some personal training sessions
- Pain Increases with Standing, Walking and very stiff first thing in the morning
- Pain decreases with rest, ice and with passive stretching
- Not taking Tylenol nor ibuprofen
- R knee pain - no radicular symptoms. General tenderness around the right knee. No point specific tenderness. Continued numbness near the right knee.
- Gait: antalgic , especially first steps and after she's been up walking for > 1 hour
- Sensation: Intact light touch- except right around the knee- some post surgical numbness

[4/6/2017, Elizabeth M Senoraske MPT, River Valley Physical Therapy]

- Patient felt better after first treatment, but then worked 12-hour shifts the last few days, and is again sorer. She did feel knee therapy was helpful. Initial rotation on bike today was uncomfortable due to ROM flexion loss. She was better as went along.

[4/11/2017, Elizabeth M Senoraske MPT, River Valley Physical Therapy]

- Patient's knee is feeling better since last visit, however she has a sore back from raking for 4 hours on Sunday. It is slowly improving, but still very sore today. Has not done much with knee exercises as the back has been so sore.
- Not much swelling noted. ROM increased to AROM 116 flexion, PROM 1 degrees extension.
- Assessment: Patient presents with about 5 week history of increased pain and swelling in the R knee (her TKA was 8/16), but she is improving. Walked on treadmill for about 5 minutes with smooth and controlled gait.

[7/10/2017, Elizabeth M Senoraske MPT, River Valley Physical Therapy]

- DISCHARGE SUMMARY: Pt last seen on 4/11/17. Patient presented with about 5 week history of increased pain and swelling in the R knee (her TKA was 8/16), but improving. Walked on treadmill for about 5 minutes with smooth and controlled gait. Cont HEP. Patient was to continue with PT as needed. Had to cancel her next visit and did not reschedule so discharge to HEP at this time.

[11/13/2018, Joshua B Johnson MD, Ancillary Procedure in Lakeview Hospital Radiology Nuc Med] [Sprafka Records 000076]

- NM Bone scan, 3 Phase
- Diagnosis: Right knee pain, unspecified chronicity
- INDICATION: Right knee pain, right TKA placed 2 years ago in August. Ongoing pain since.
- COMPARISON: Radiographs 10/29/2018.
- TECHNIQUE: 24.1 mCi of technetium 99m MOP were administered intravenously and planar images of the knees were obtained in blood flow, blood pool, and delayed phases.
- FINDINGS: Right TKA with patellar resurfacing. Asymmetric mildly increased blood flow and moderately increased blood pool uptake about the right knee suggesting nonspecific hyperemia or inflammation, infection not excluded. Delayed phase images depict moderate diffuse uptake about the right TKA, which is nonspecific but still could be postoperative. No findings specific for loosening.
- CONCLUSION:
    1. Hyperemia about the right knee. Infection is not excluded.
    2. No findings specific for right TKA loosening.

[07/07/2020, Michael R Anderson, DO, Woodlake Clinic, Corporate Woodbury Office]

- Foot & Ankle Assessment: Insertional Achilles tendinopathy, left lower extremity:
- Julie is a very pleasant 58-year-old female who comes in today for evaluation of left heel pain. She is been experiencing pain in the left heel for the last 3 months or so. She has not sought care for this aside from seen her regular doctor who suspected bone spurs. She presents for initial evaluation. She has pain with usual typical activities including work and chores around the house. So far she is not particularly disabled but, does find her symptoms persistent and obnoxious.
- Patient Link information reviewed and incorporated into the chart. Patient reports no other musculoskeletal or neurologic complaints. Patient reports primary issue is with the left foot. Symptoms began suddenly over the last 12 week(s). The timing of the symptoms is constant. The symptoms are not related to any known cause. Patient is currently experiencing pain.. Current pain is 6/10. Worst pain is 9/10. She describes the pain as aching. Patient notes symptoms to be unchanged. Exacerbating factors: walking, climbing stairs and getting out of a chair. Relieving factors/treatments: over-the-counter medications. She was previously evaluated by a primary care provider.
- Discusses conservative therapy and surgical options. Holding off on surgery for now favor of an initial conservative approach including physical therapy for eccentric Achilles stretching. Iontophoresis can be included. Heel lifts were dispensed. A prescription for nitroglycerin patches was prescribed to help with increased blood flow to the area to hopefully see some healing. Not all patients respond to nonoperative care however it is worth trying nonoperative care. Will see her back in 6-8 weeks.

[3/12/2019, Elizabeth M Senoraske MPT, River Valley Physical Therapy]

- Diagnosis Codes: Pain In left ankle and joints of left foot
- Mechanism of Injury Insidious - pain just seemed to start- maybe with limping due to R knee issue, or with standing/ walking on cement floors all day. No incident noted.
- Pain increases with sitting, walking , transitions sit to stand especially after sitting for a while, pain wakes at night at least 1x/ night.

- Pain decreases with rest, moving the ankle (pumping, circles)
- Medical History: Arthritis , R TKA, HTN
- Takes Ibuprofen
- Pt saw specialist and he suggested PT, heel lift and anti-inflammatory patch for her pain. If these do not work, he suggested surgery for bone spur removal. Pt does not want surgery so she is hoping these other options help. Ibuprofen helps take the edge off, but no lasting relief.
- Diagnostic Testing X-ray bone spurs in the Achilles and increased bone growth at Achilles attachment on posterior heel , left.
- Knee muscle strength 5/5 , bilaterally
- Assessment: Patient presents with about a 4 month history of left heel pain that just seemed to start. Saw specialist and with x-ray diagnosed with bone spurs and increased bone growth at the posterior heel into the Achilles. She tried a small lift, but this is irritating (still trying). She is here to try PT and also has an anti-inflammatory patch for the area 12 hours on/12 hours off. Surgery is the other option. She tolerated the evaluation and treatment except for static stretching of the calf /Achilles and calf raises.

[06/10/2020, Kristoffer M Breien MD, Corporate Office-Woodbury MN]

- Assessment: Painful right total knee arthroplasty, suspect tibial loosening, initial encounter.
- Plan
  1. Nuc Med 3-Phase Bone Scan; Status: Active; Requested for: 10Jun2020;
  2. XR Knee 3V, Right; Status: Complete; Done: 10Jun2020
     - I had a nice discussion today with her regarding her knee. She has fairly classic startup pain. She has some lucency around the tibial keel, and she does have a DePuy Attune, which was placed in 2016. We discussed the fact that this knee has a bit of a track record in terms of delaminating from the cement, and she has significant suggestion thereof. She also has pain over the tibia, not particularly the femoral side of her knee. In the end, I would like to obtain a bone scan to confirm or further delineate if she does have true loosening. It has been almost 4 years since her surgery, so I think it would give valuable information. We will discuss the results with her thereafter.
     - Subjective: Julie is a very fit, pleasant, 59-year-old female seen today for evaluation of her painful right total knee arthroplasty. She reports a replacement of her right total knee that was done which she recalls in August of 2016 at a different group. She reports that ever since the surgery, she has had pain in that knee. It just felt like it never quite took. Pain particularly with activity and weightbearing. She says it has persisted. She has had multiple x-rays. She did bring the previous x-rays with her. She reports that the pain is more over the tibia than the femur and worse when she goes from a seated to standing position especially for the first few steps. It sounds like fairly classic startup pain. She does not show any evidence of infection or persistent swelling in the knee. The patient's current medical problems, past medical history, family history, social history, and review of systems are all as per the intake sheet, which the patient completed today, and I reviewed, and it was incorporated in the medical record. The patient reports no other musculature or neurologic complaints.
     - Patient reports primary issue is with the right knee. Symptoms began suddenly 6 year(s) ago. The timing of the symptoms is constant. Symptoms occurred while patient was at work. The symptoms resulted from a twisting motion, lifting, bending and repetitive motion.

- Current pain is 3/10. Worst pain is 7/10. She describes the pain as aching. Associated symptoms include stiffness, weakness and giving way. Patient notes worsening of symptoms.
- Exacerbating factors: walking, standing, climbing stairs and getting out of a chair. Relieving factors/treatments: ice, rest, sitting and over-the-counter medications.
- Objective: On exam, the patient is awake, alert, and oriented x3. Pleasant. Well nourished, well developed with a positive affect. Walks with a reasonable gait. Examination of the lower extremities reveals intact posterior tibial pulses. Normal skin without lesions. No lymphedema. No venous stasis changes and intact gross sensation in both lower extremities. There is 5/5 quadriceps and hamstring strength bilaterally.
- Examination of both knees, the left shows smooth, fluid, full range of motion. No instability. No crepitance. Solid varus/valgus. Solid anterior/posterior drawer. Midline patella with mild crepitance. Negative patellar grind. She has 5/5 quadriceps and hamstrings bilaterally. Examination of the right knee shows a well-healed incision. No real effusion. Skin is intact. No erythema. No cellulitis. She comes to full extension. Flexion is to 115 or 120 degrees. The knee is stable to varus/valgus and appropriate anterior/posterior drawer. No real pain with palpation over the distal femur. Minimal pain with palpation around the patella. Exquisite tenderness with palpation of the medial and lateral tibial plateau.
- Imaging and Test Results: X-rays obtained and reviewed today, 3 views of the right knee including AP of both knees, lateral of the right knee, and a patellofemoral view of both knees, show a DePuy Attune type total knee. Lateral view obtained today and compared with previous views does show what looks to be a little lucency between the cement mantle and the anterior portion of the tibial stem.

[06/23/2020, Joshua C. Zawacki, DO, 3-phase radionuclide Bone Scan]

- EXAM: 3-PHASE RADIONUCLIDE BONE SCAN OF THE BILATERAL LOWER EXTREMITIES
- CLINICAL: 59-year-old female with right knee pain for approximately 6 years. History of right total knee arthroplasty surgery in 2016.
- COMPARISONS: X-rays 6/10/2020 and 10/29/2018.
- TECHNICAL: After intravenous administration of 25 mCi of Tc-99m-HDP via left antecubital access, blood flow images were obtained at 5-second intervals, followed by 5-minute blood pool images. Then, after 2 hour delay, delayed scintigraphy was performed.
- INTERPRETATION: Minimal faint tracer uptake about the right knee arthroplasty hardware on the blood flow and blood pool images. Moderate increased tracer uptake is also demonstrated about all components of the right knee arthroplasty hardware on the delayed images.
- Mild increased tracer uptake involving the left knee on the delayed images is likely degenerative in nature. No significant increased tracer uptake involving the bilateral hips on the delayed images.
- CONCLUSION:
  1. Increased tracer uptake about the right knee arthroplasty hardware is most prominently seen on the delayed images and concerning for changes of osteolysis/hardware loosening.
  2. Mild tracer uptake involving the left knee on the delayed images is likely degenerative in nature.

[07/07/2020, Michael R Anderson, DO]

- Subjective: Julie is a pleasant 59-year-old female who comes in today for evaluation of her left Achilles status post insertional Achilles debridement, gastrocnemius recession, Haglund removal. Doing very well. She continues to use the cam boot but has no significant pain or disabling symptoms in her left heel.
- Assessment: Status post left insertional Achilles debridement, gastroc recession. Date of surgery, 3/16/2020.
- Active Problems
    1. Denied: Anticoagulant prescribed
    2. Foot pain
    3. Gait disturbance
    4. High blood pressure
    5. Intractable left heel pain
    6. Non-smoker
    7. Right knee pain
    8. Thyroid disease

[07/8/2020, Elizabeth M Senoraske, MPT]

- Injury Date 8/16/2016
- Revision TKA Surgery is scheduled for 9/15/2020.
- Chronic pain for years, continued even after R TKA.
- Insidious -Patient t had pain for about a year leading up to R TKA 8/16/16 and since then, she continued to suffer.
- Pain increases with Standing, Walking , aching while lying down as well, getting up to walk.
- Pain decreases with rest, ice , ibuprofen
- Worst Level 7/10
- Functional Outcome Testing: Lower Extremity 29/ 80: 36% physical function/ 64% impairment (LEFS scale)

[7/28/2020, Elizabeth M Senoraske MPT, River Valley Physical Therapy]

- Mechanism of Injury: Insidious - patient had pain for about a year leading up to R TKA 8/18/16 and since then, she continued to suffer.
- Pain increase with: standing, walking , aching while lying down as well, getting up to walk
- Pain decreases with: rest, ice, ibuprofen
- Moderate to severe pain, limited activities due to pain. Minimal swelling.

[8/17/2020, Elizabeth M Senoraske MPT, River Valley Physical Therapy]

- Subjective: Patient reports some expected mm soreness with exercises as well as some joint soreness in the knee. She is careful not to push things when her knee is sorer. Exercises are going well.
- Assessment: Pt presents about 4 weeks pre-op for a right TKA revision due to a faulty part within the prosthesis. Her previous TKA was almost 4 years ago. She presents to work on strengthening and balance prior to her surgery to help with the recovery.

[09/15/2020, Kristoffer M Breien MD, Revision Operative Report, Woodwinds Hospital, Woodbury MN]

- INDICATION: Ms. Julie M Sprafka is a very pleasant 59 year-old female. She underwent total knee arthroplasty about 5 years ago. She has ongoing pain particularly with ambulation. Notable start up pain. Bone scan has shown increased uptake around her components particularly the tibia. She has a DePuy first generation Attune total knee in place. There is some suggestion of lucency along the anterior portion of the tibial keel. Her symptoms are entirely consistent with loosening with pain over the tibia. Consequently, the risks and benefits of revision total knee arthroplasty were discussed with patient and the patient elected to proceed.
- FINDINGS: Loose tibial component with failure of cement mantle from prosthesis
- IMPLANTS
  1. DePuy, Sigma MBT size 3 revision tibial tray with a 53 mm sleeve and a 75 x 16 stem extension
  2. DePuy, Sigma TC 3 femoral component with a 46 mm femoral sleeve and a 75 x 18 mm stem extension
  3. DePuy, TC 3 all polyethylene articular insert, rotating platform, size 4, 12.5 mm thickness.
- PROCEDURE: Once consent was obtained and operative site marked in the preop holding area. patient was brought to the operating room. Anesthesia was established without difficulty. The patient was then placed in the supine position. All bony prominences and superficial nerves were padded appropriately. The right lower extremity was sterilely prepped and draped in the usual fashion.
- A longitudinal incision was made over the knee following her previous scar extending it somewhat proximally. Dissection carried down through subcutaneous tissue. Medial parapatellar arthrotomy was created. Some redundant scar was debrided medial lateral gutter and in the supra patellar pouch. There was a physiologic amount of very benign fluid in the knee. Preoperative CR P and sed rate were entirely normal so there was no suspicion for infection. Components were then inspected. Femoral component looked to be solid. Tibial component showed slight micro motion at the implant cement interface. I removed the polyethylene component with an osteotome. I then brought the tibia forward and tapped it with the drift from below. The tibial implant separated from the cement mantle, which remained intact with the tibia with just 1 tap. This confirmed our suspicion. Attention was turned to the femoral side. Reciprocating saw was passed behind the femoral component medial and lateral and anterior and it was tapped free with minimal bone loss.
- The tibia was further exposed and a few more taps brought the entire tibial component out of the wound by hand. The entirety of the cement mantle stayed intact with the tibia. There was no remaining cement on the back of the tibial component. The osteotomes and rongeur were then used to better debride the tibial cement remaining off the proximal tibia. We then reamed up to a 16 stem gently and broached to the 53 mm sleeve. We then made a freshening cut on the tibia off the top of the sleeve. Trial component was created and placed. Attention turned to the femur.
- Femur was similarly reamed and broached and then a distal freshening cut of 2 mm was performed. It sized nicely to a 4 component and the 4 cutting block was placed and freshening cuts completed. There was no need for augmentation. This trial was also built and placed. The knee was then reduced with a 10 mm polyethylene followed by 12.5 mm polyethylene, which restored nice flexion extension gaps and nice varus valgus stability. Patella tracked well.

- All trial components were removed. The final components were opened and created on the back table. Cement was mixed and after meticulously drying the bone all components were cemented and held till firm. Final polyethylene was engaged. The knee was taken through range of motion found to be nicely stable. Patella tracked well. Good flexion extension gaps. Wound was then copiously irrigated. The arthrotomy was then closed with #2 interrupted Vicryl suture followed by 0 and 2-0 interrupted Vicryl suture in the deep dermis and final skin closure.

[9/21/2020, Elizabeth M Senoraske MPT, River Valley Physical Therapy]

- Mechanism of Injury Insidious -Patient had a TKA on the R about 5 years ago but had ongoing pain with ambulation. It was found there was an issue with her hardware and a revision was suggested.
- Pt presents sore, with a SP cane and with a slow, antalgic gait. She reports using a CPM 3x / day which she tolerates well, has not done much else up until yesterday. She was in a lot of pain the first 4 days but slowly improving now. Moderate swelling noted.
- Assessment: Patient presents about 1 week post op R TKA- a revision. She presents with a SP cane and a moderate antalgic gait. Reports starting use of cane today, otherwise using a walker. She is in some expected pain, though a few days ago she was in significant pain. Patient t using a CPM 3x / day. She did well with the evaluation and treatment, though movement feels good, some soreness afterwards.

[10/5/2020, Elizabeth M Senoraske MPT, River Valley Physical Therapy]

- Subjective: Patient reports really worked the knee over the weekend with gardening and cleaning the house. Did okay with these things, but more sore afterwards. Extension at home has been difficult (with husband pushing down- difficult to relax).
- Objective: Right knee ROM 6-108 and gait much improved. Able to walk with a good heel toe pattern and use of SP cane. Cont swelling in the knee but improving. Some redness and warmth over the lateral/ inferior aspect of the knee with tenderness to touch. Pt thought maybe due to overuse. Patient will monitor if any worse and to call MD. No fever noted. Almost looks burned- ice.
- Assessment: post TKA-revision. She presents with a SP cane and slight antalgic gait. She is In some expected pain, but improving. Pt using a CPM 3x / day. Sore during extension> flexion during treatment, but overall better afterwards with swelling.

[10/15/2020, Elizabeth M Senoraske MPT, River Valley Physical Therapy]

- Subjective: Patient continues to have the redness and warmth over the skin (laterally) and saw MD yesterday. He said there is definitely something going on , they are just not sure what it is. They took a vile of fluid from the knee for testing and will figure out the right course of action from there. Tender to touch esp. over the lateral aspect of this red area. Exercise- strength 1x / day only.

[12/14/2020, Kristoffer M Breien MD]

- Assessment: Three months status post revision right total knee arthroplasty, subsequent encounter.
- Plan X-ray Knee 1 or 2V, Right; Status: Complete; Done: 14Dec2020
- At this point, everything appears to be coming along appropriately. I wrote her a prescription for a handicapped sticker that she can use through the winter months since she is still using a cane and protecting that side. We discussed anti-swelling measures as she still has issues with that, particularly when she is now returning back to work and cannot elevate the knee all the time. She will continue to use her compressive hose. In regard to the knee, she will continue working on her strength, gait, and motion. I plan to follow up with her in 6 months.
- Subjective: Julie is seen today about 3 months out from total knee arthroplasty revision. All in all, she is making progress.
- Objective: She still uses a cane and still has some aching soreness around that knee. She is now 2 degrees, maybe 3 degrees short of full extension. Her flexion is very good to about 115 or 120 degrees. The knee is stable. The wound is nicely healed. No erythema. No cellulitis. Only mild discomfort and mild temperature around that knee. Neurovascularly intact lower extremities bilaterally.
- Imaging and Test Results: X-rays obtained and reviewed today, AP and lateral views of that right knee show well-seated, well cemented total knee components without loosening, fracture, or complication.
- Active Problems
    1. Aftercare following right knee joint replacement surgery
    2. Denied: Anticoagulant prescribed
    3. Failed arthroplasty
    4. Foot pain
    5. Gait disturbance
    6. High blood pressure
    7. Intractable left heel pain
    8. Non-smoker
    9. Redness of skin
    10. Right knee pain
    11. Status post total right knee replacement
    12. Thyroid disease
- Surgical History
    - History of Hysterectomy
    - History of Knee replacement
- Family History of diabetes mellitus
- Social History
    - Currently working
    - Never a smoker
    - No alcohol use
    - Non-smoker
- Julie is able to return to work as of 11/20/20, with restrictions:
    1. no standing >10 minutes at a time
    2. allow frequent breaks as needed during the day
    3. no lifting > 10 lbs.

    - please allow to do brace treatments 5 times per day
    - Restrictions in affect until next visit, 12/2/20.
- Work activity release signed on behalf of Kristoffer Breien MD (NPI: 1194793554)

[03/03/2020, Michael R Anderson MD, Foot & Ankle Follow up]
- 5'6" tall , 220 lb, BMI 35.51

[04/08/2021, Elizabeth M Senoraske, M.P.T.]
- Pt was last seen on 1/4/2021 for her 22nd PT visit after her TKA revision. At that time, she was overall doing well. She walks around her home independently, but uses a SP cane out of the house for comfort and to avoid limping. She used a cane for years prior to this revision, so it has been a hard habit to break. The knee continued to swell after a long work day and especially towards the end of the week, but then the swelling would go away. There was very little pain with the swelling however. She reported very manageable discomfort. Patient is to continued to use passive extension splint 2x / day at work and 4x / day on the weekends. Stretching continued to feel good and patient felt functionally strong. She was able to go up and down the steps with an alternating pattern. ROM extension to 5, flexion to 116. Strength tests 5/5. SL balance average 20-30 seconds and no pain. Pain at worst 2 / 10 and most of the time 0 / 10. Pt takes extra strength Tylenol once in a while, but infrequently. Patient reports she sleeps well with no interruption due to knee pain 7/7 nights. LEFS: 52/80: 65% function. LEFS without the running and hop questions 52/64: 81% physical function. Plan was to hold chart and patient was to continue with HEP on own and call if needed. She continued to work on knee extension > flexion and functional strength and endurance.

[8/30/2021, Kristoffer M Breien MD]
- One year status post revision right total knee arthroplasty, doing well, subsequent encounter.
- Subjective: Julie is seen today for follow-up of her revision total knee arthroplasty. She is coming along beautifully. She is now essentially 1 year out from this. She feels great. She has no pain. She walks with a normal gait. Her wound has a well-healed scar. She has no swelling in the knee, and the knee is stable. The patient's current medical problems, past medical history, family history, social history, and review of systems are all as per the intake sheet, which the patient completed today, and I reviewed, and it was incorporated in the medical record. The patient reports no other musculature or neurologic complaints other than as per the History of Present Illness.
- Patient Link information reviewed and incorporated into the chart. Patient reports no other musculoskeletal or neurologic complaints.
- Objective: On exam, the patient is awake, alert, and oriented x3. Pleasant. Well nourished, well developed with a positive affect. Walks with a reasonable gait. Examination of the lower extremities reveals intact posterior tibial pulses. Normal skin without lesions. No lymphedema. No venous stasis changes and intact gross sensation in both lower extremities. There is 5/5 quadriceps and hamstring strength bilaterally. Examination of both knees shows range of motion 0 to 120 degrees bilaterally. Both knees are stable to varus/valgus. Appropriate anterior/posterior drawer. Well-healed scar on the right. Normal skin. No erythema. No cellulitis. No effusion in either knee. No pain around either knee.

- Imaging and Test Results: X-rays obtained and reviewed today; AP of both knees and lateral of the right knee show well-seated, well positioned revision total knee components without issue. No polyethylene wear. No lysis.
- Review of Systems: Patient had no falls in the past year
- Active Problems:
  1. Aftercare following right knee joint replacement surgery
  2. Denied: Anticoagulant prescribed
  3. Failed arthroplasty
  4. Foot pain
  5. Gait disturbance
  6. High blood pressure
  7. Intractable left heel pain
  8. Non-smoker
  9. Redness of skin
  10. Right knee pain
  11. Status post total right knee replacement
  12. Thyroid disease

[4/8/2021, Elizabeth M Senoraske MPT, River Valley Physical Therapy]

- Patient was last seen on 1/4/2021 for her 22nd PT visit after her TKA revision. At that time, she was overall doing well. She walked around her home independently, but uses a cane out of the house for comfort and to avoid limping. She used a cane for years prior to this revision, so it has been a hard habit to break. The knee continued to swell after a long work day and especially towards the end of the week, but then the swelling would go away. There was very little pain with the swelling however. Patient reported very manageable discomfort.
- Patient continued to use passive extension splint 2x/day at work and 4x/day on the weekends. Stretching continued to feel good and patient felt functionally strong. She was able to go up and down the steps with an alternating pattern. ROM extension to 5, flexion to 116. Strength tests 5/5. SL balance average 20-30 seconds and no pain. Pain at worst 2/10 and most of the time 0/10. Pt takes extra strength Tylenol once in a while, but infrequently. Patient reports she slept well with no interruption due to knee pain 7/7 nights. LEFS: 52 / 80: 65% function. LEFS without the running and hop questions 52 / 64: 81 % physical function. Plan was to hold chart and to continue with HEP on own and call if needed. She continued to work on knee extension> flexion and functional strength and endurance.

Medical records document that following her primary Attune and revision Sigma TKA procedures, Julie Sprafka participated in numerous physical therapy sessions, and she completed home exercises to improve her range of motion (ROM), right limb strength and general gait. Her physical therapist's notes[C] indicated that Julie Sprafka limped and used her cane for walking stability for years following her index right TKA, and required retraining to restore normal gait following her revision TKA, and on discharge from PT was still using her cane when walking outside of the house for comfort and to avoid limping.

My February 16, 2023 visual inspection of Julie Sprafka's explanted Attune TKA components documented that there was little bone cement remaining attached to the tibial base tray as

[C] Sprafka Records 000134, 156

described by the revising surgeon, Dr Breien, in his operative notes. The femoral implant, however was well coated with bone cement.

Julie Sprafka's devices were inspected in the as-received condition. The device were received in specimen containers labeled as containing formalin. The devices were still moist and emitted a formalin vapor . The device were not soaked, processed or cleaned of biologic debris. Microscopic examination of the cement pocket undersurface of the base tray revealed small regions with what appeared to thin layer of attached bone cement or biologic material captured in or one the surface. Macroscopic photographs were taken of each component, and microscopic photographs[D] were taken around the perimeter of the tibial baseplate undersurface .

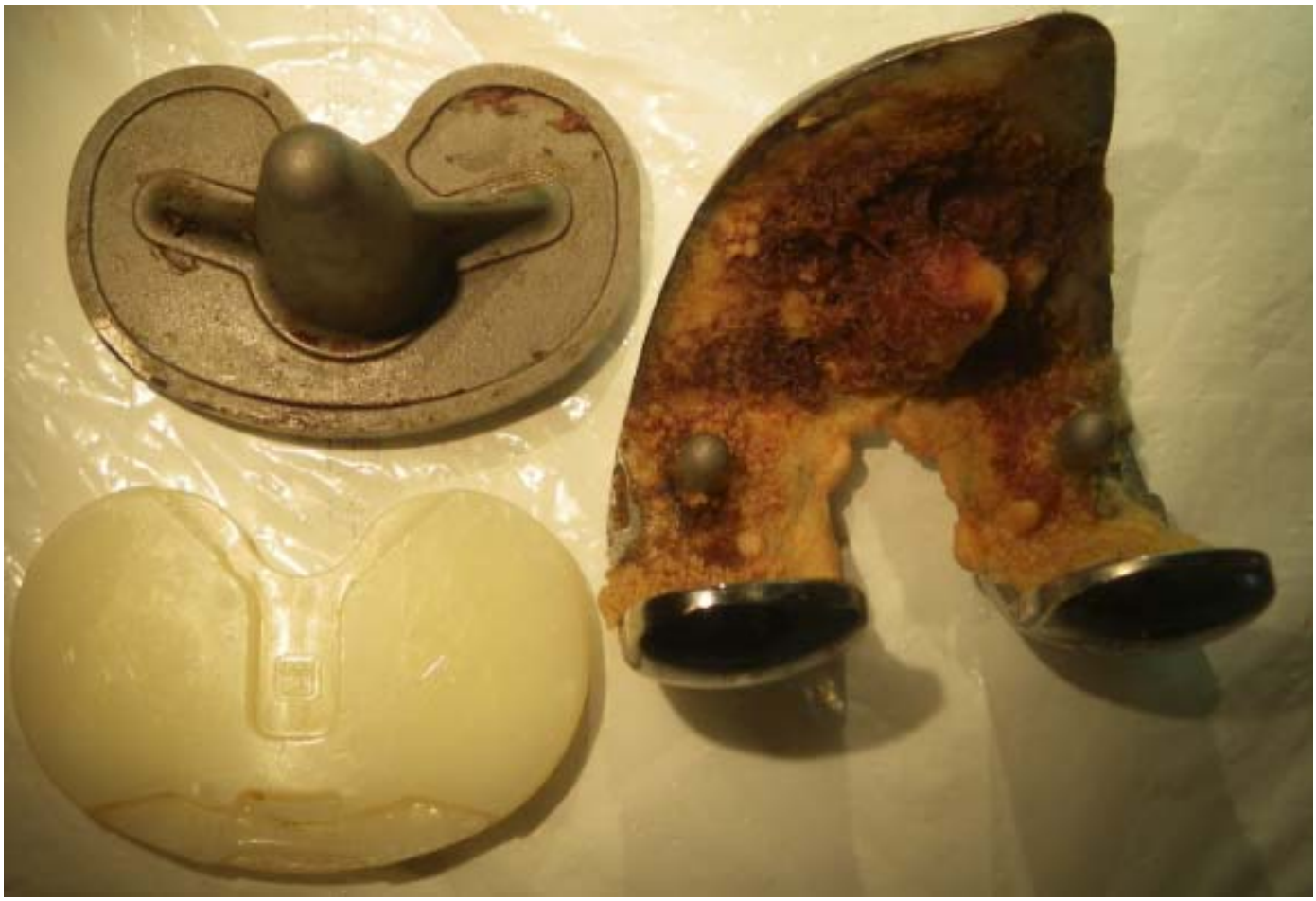


Figure 1: Group photograph of the three Attune TKA devices explanted from Julie Sprafka on October 15, 2020. **Upper Left**-Tibial baseplate. Some biologic debris is noted. Cement is not adherent to the majority of the visible surface. **Lower Left** - AOX Ultra high molecular weight polyethylene(UHMWPe) with tibial liner . Baseplate locking surface is seen. **Right** - Bone-contacting surface of the femoral implant, bone cement remains attached to the CoCr surfaces. Biologic material/blood is visible on the cement surface.

[D] Microscopic photographs were taken at the same magnification.

Figure 2 : The bearing surfaces of Ms Sprafka's explanted knee implant are shown**. Left -** UHMWPe liner, **Right** - Femoral condyles.

Figure 3: Images of Ms Sprafka's explanted Attune tibial baseplate undersurface. The majority of the surface has no retained bone cement. A smooth blast surface finish is seen on the shallow cement pockets and keel region.

Figure 4 : Images of Ms Sprafka's explanted Attune tibial baseplate showing the part number (left image) and the baseplate bearing bearing snap-lock attachment surface (right image).

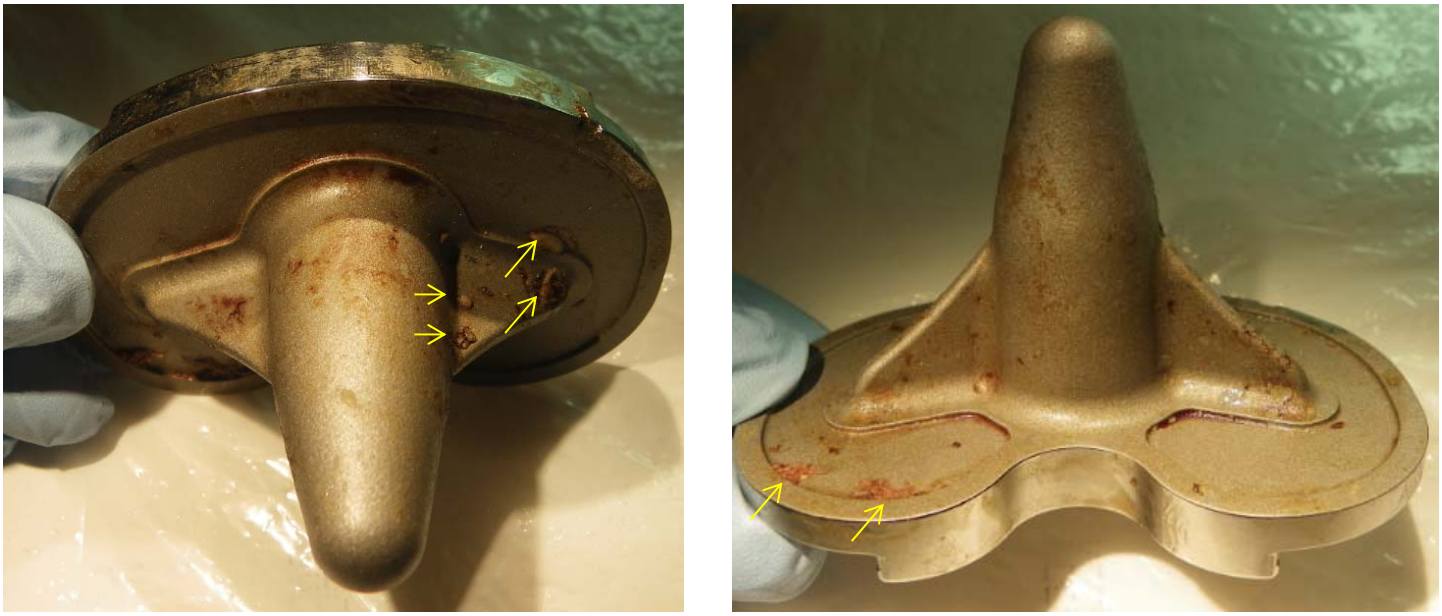


Figure 5: More images of Ms Sprafka's explanted Attune tibial baseplate undersurface. The majority of the surface has no retained bone cement. A smooth blast surface finish is seen on the shallow cement pockets and keel region. Bothe region a have biologic debris and are essentially devoid of cement. Small zones of bone cement covered with biologic debris were identified near the posterior perimeter and on a keel.

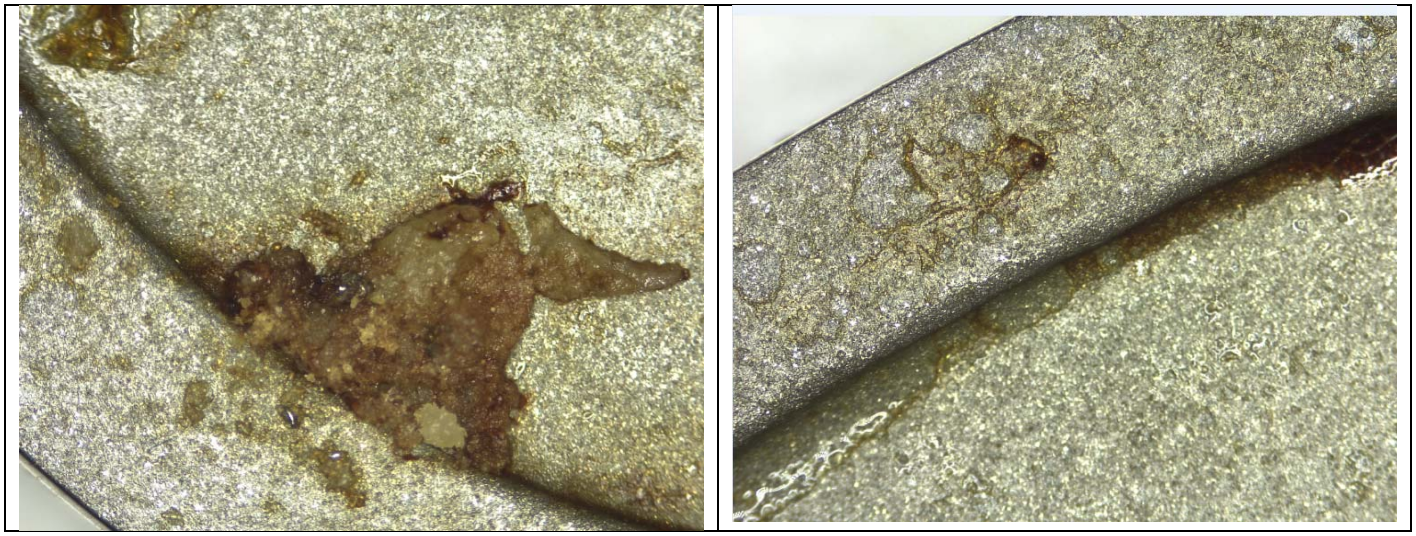


Figure 6: Left - This image shows one of the perimeter locations with a bone cement fragment. Right- This image shows the typical appearance of the tibial baseplate implant at the perimeter. Biologic residue is still present.

D. TOTAL KNEE REPLACEMENT BACKGROUND & THE PRODUCT INVOLVED IN THIS INCIDENT

The knee is a synovial joint formed by the junction of the femur, tibia and patella (**Figure 7**) enclosed by a multi-layered, strong, fibrous capsule. All bearing surfaces are covered by a layer of articular cartilage that, in combination with synovial fluid, allows proper lubrication of the joint for extremely low friction. The cartilage also absorbs energy and distributes loads uniformly to the underlying bone. This distribution of load is aided by two intra-articular, semi lunar shaped rings, referred to as the menisci, which accommodate for the incongruence of the articulating surfaces. The menisci, along with cruciate and collateral ligaments, play an important part in joint stabilization and guiding joint motion. The extracapsular anterior and posterior cruciate ligaments (named according to their attachment on the tibia) prevent hyperextension and anterior femoral displacement, respectively. The extracapsular collateral ligaments (fibular and tibial) give the knee joint side stability and prevent medial rotation of the femur during full extension.

Painful knees are a common problem in the middle-aged and elderly populations. There are several treatments for early stage arthritis that can help alleviate pain, and return people to their daily activities. As some point, however, painful knees interfere with quality of life to such a point that something has to change. When treatments such as anti-inflammatory medications, cortisone injections and physical therapy fail to improve the situation, total knee replacement can be an option. X-rays may show bone spurs and loss of cartilage in the knee joint space.

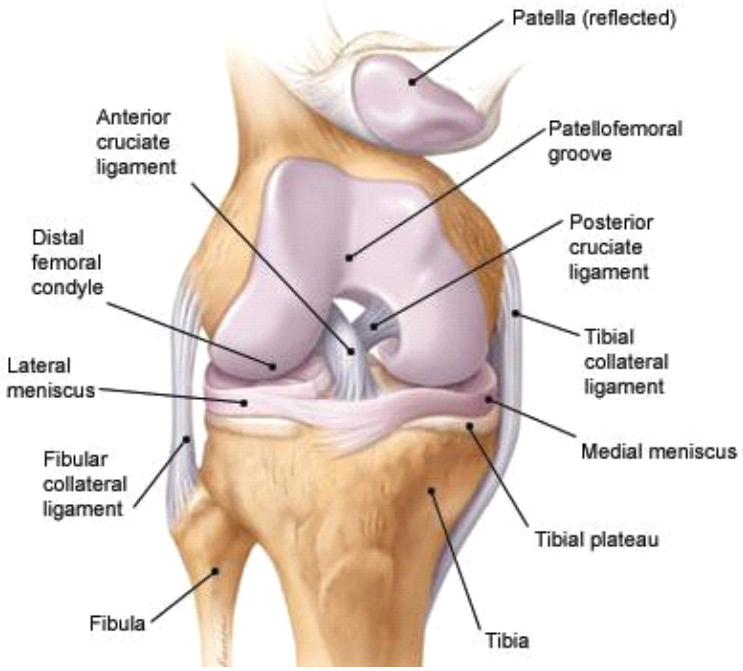


Figure 7: Right Knee Anatomy- Note: Julie Sprafka had her right knee replaced using DePuy Attune implants.

The most common reason for needing total knee replacement surgery is osteoarthritis, or degenerative joint disease that is a disease that causes the breakdown of cartilage. This is often referred to as 'wear and tear' arthritis, although these days we are beginning to understand that osteoarthritis is more than simply a condition of joint aging.

As the cartilage surface on the ends of the bones is worn away, the normal mechanics of the knee joint are altered, and the exposed bone can cause pain. Common symptoms of severe arthritis of the knee joint include swelling of the joint, pain, bow-legged or knock-kneed

deformity and loss of motion. When a knee replacement is performed, the bone and cartilage on the end of the thighbone (femur) and top of the shinbone (tibia) are removed. This is performed using precise instruments to create exact surfaces to accommodate the implant. A metal and plastic knee replacement implant is then placed to function as a new knee joint. Depending on the condition of the cartilage on the undersurface of the kneecap, this may also be replaced. Some of the implants are cemented into the bone, and some are fit snuggly into place such that bone grows into the implant.

Total knee replacement surgery is performed to replace the cartilage of the knee with metal and plastic. When a knee replacement is performed, the bone and cartilage on the end of the thighbone (femur) and top of the shinbone (tibia) are removed **(Figure 8a**). This is performed using precise instruments to create exact surfaces to accommodate the implant. A metal and plastic knee replacement implant is then placed to function as a new knee joint **(Figure 8a, b).** Depending on the condition of the cartilage on the undersurface of the kneecap (patella), this may also be replaced. Some of the implants are cemented into the bone, and some are fit snuggly into place such that bone grows into the implant.

The femur and tibia are resurfaced with metallic components; however, a tibial tray or baseplate holds the tibial polyethylene insert (aka. tibial liner or articular surface) that articulates with the metallic femoral component. The patella may also be resurfaced with a polyethylene (plastic) button that slides along the trochlear groove of the femoral component.

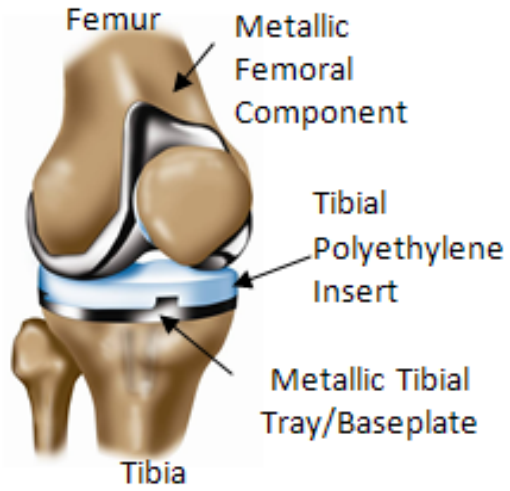


Figure 8a: Cruciate retaining (CR) knee implant (no posterior stabilizing post or housing). A standard liner constraint is shown in this image. There is no post or housing to interact in the center of this implant.

Figure 8b: PCL sacrificing posterior stabilized knee implants (PS knee implants). Orange arrow points to the stabilizing post tibio-femoral implant interaction, which assures some roll back.

The "gold standard" is to secure TKA implants to bone using polymethyl methacrylate (PMMA) bone cement. However, press fit of a porous-coated femoral implant to the bone on the femoral side is relatively common.

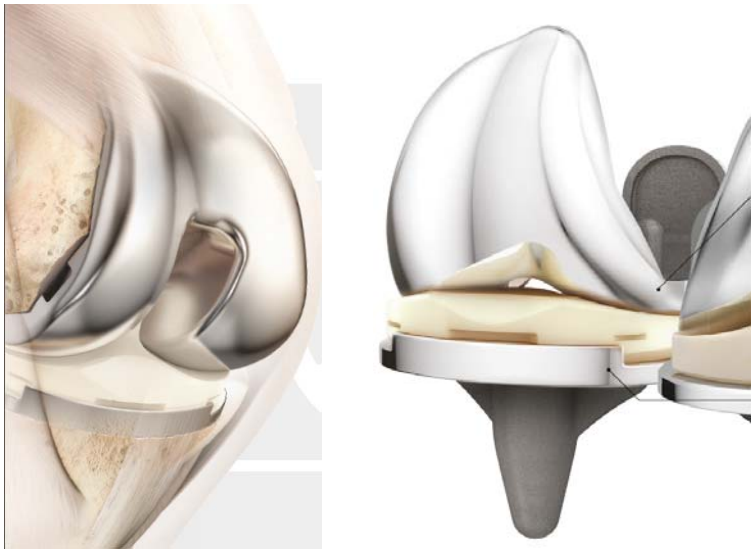
The product involved in this incident was a refined CR knee, the Attune CR fixed bearing Knee, which was comprised of a metallic femoral component, a metallic tibial baseplate, a mating CR

insert and a medialized dome patella. The metallic components were secured to Julie Sprafka's bones using bone cement, also manufactured for and sold by DePuy.

1	2	3	4	5
Bone Cement , 2 packages (records state Quickset Mfg by J&J Cordis Webster[E]) Matl: Methylacrylate Copolymer, methylmethacrylate monomer Ref: 3322-020 Lot: 8280491	DePuy Attune Tibial Base Fixed Bearing Size 6 Cemented Matl: CoCr Ref: 1506-00-005 Lot No.: 8318475	DePuy Attune Tibial Insert Fixed Bearing Cruciate Retaining Size 6 5mm AOX Matl: Antioxidant UHMWPe Ref: 1516-20-605 Lot: C42624	DePuy Attune Femoral CR Size 6 5 mm Right Cemented Matl: CoCr Ref: 1504-00-206 Lot: "N/A" on records	DePuy Attune Patella Medialized Dome Size 38 mm Cemented AOX Matl: Antioxidant UHMWPe Ref: 1518-20-038 Lot: "N/A" on records

The Attune knee system was initially cleared for sale in the US in December of 2010.

Figure 9: Two images of the Attune Knee CR knee assembly showing a CR femoral implant, a CR tibial polyethylene liner and a tibial baseplate as shown in the company brochure DSUS/JRC/0514/0162. The image of the left depicts a right knee implanted in transparent bon and tissues. The knee is in a flexed position. The image on the right shows similar left CR knee components oriented in extension, without any transparent bone or soft tissue.



[E] DePuy CMW 2 Bone Cement was listed, with lot numbers, in the complaint.

LOGICLOCK Tibial Base

The LOGICLOCK Tibial Base is the foundation for optimized stability and motion in the ATTUNE Fixed Bearing Knee. Unlike other knee designs, the femoral component and tibial insert match size to size every time, allowing for optimization of the tibio-femoral contact mechanics, stability, and rotational freedom throughout the range of motion.[4,5,7] This also allows a proportional PS box across the size range, which reduces the amount of bone removed in smaller patients.

The ATTUNE System allows the surgeon to independently size the femur and tibia for each patient. The LOGICLOCK Tibial Base is designed to accommodate 2-up and 2-down sizing between the tibial insert and tibial base. *The unique shape of the lock and an interference fit provides a locking mechanism that leads the industry in reducing backside micromotion.*[9]

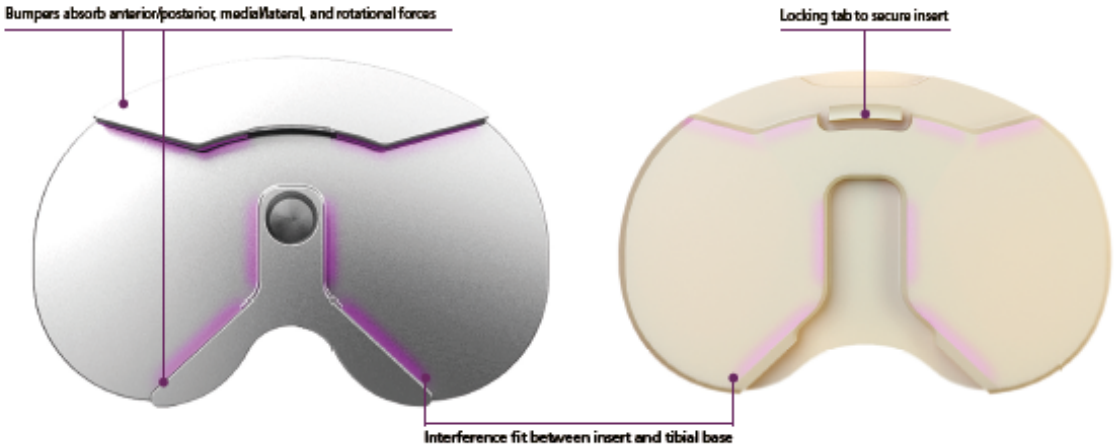


Figure 10: Images of the Attune Knee tibial baseplate and mating polyethylene liner locking features as shown in the company brochure DSUS/JRC/0514/0162.

Figure 11: Images of Attune AOX Polyethylene liners as shown in DSUS/JRC/0714/0314 Attune Knee System AOX Antioxidant Polyethylene brochure. Julie Sprafka was implanted with the device types circled in blue.

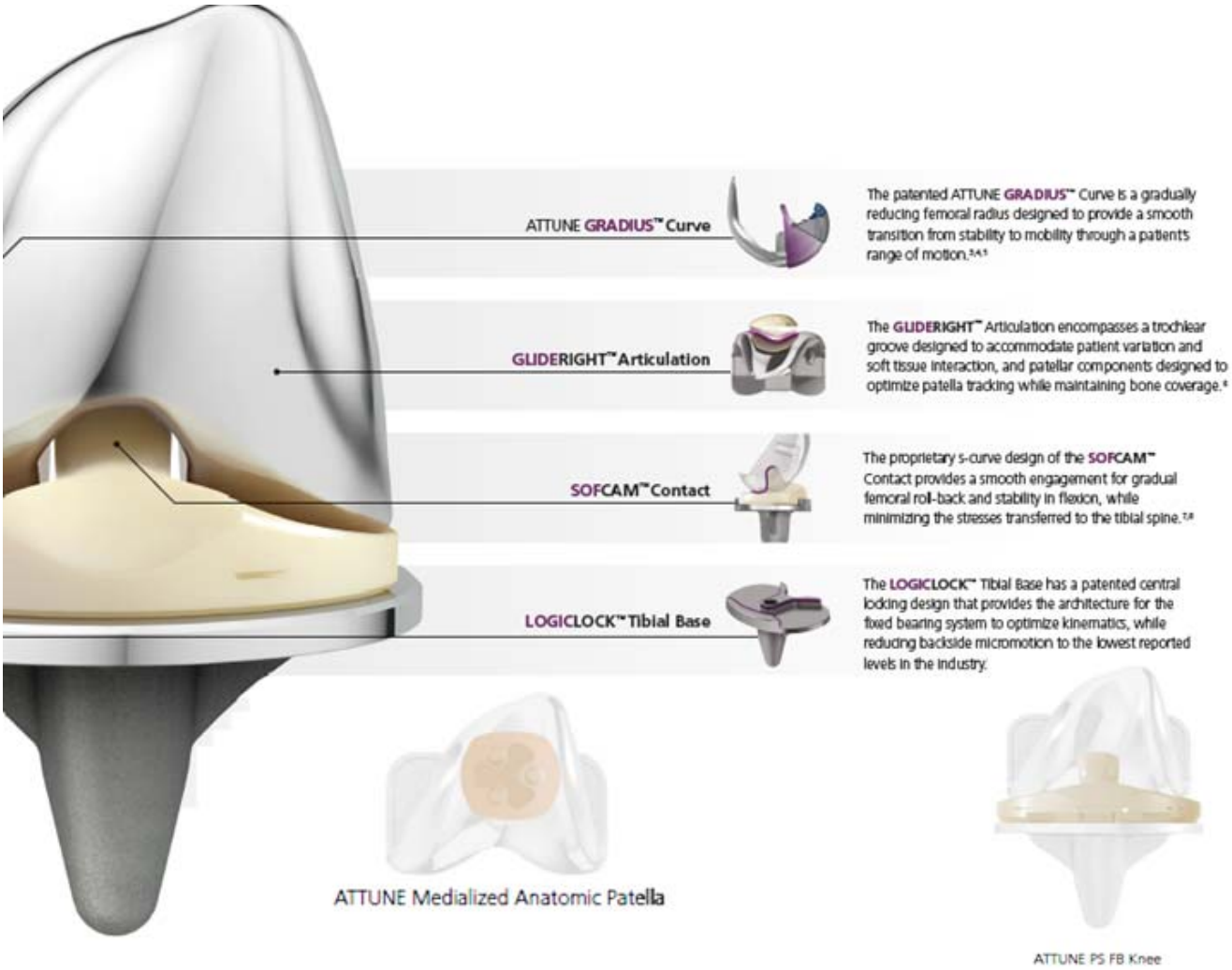


Figure 12: Images of the Attune Fixed Bearing PS total knee component from company brochure DSUS/JRC/0514/0162 Attune Knee System stabilityinmotion™.The Attune CR knee implanted in Julie Sprafka also features the GRADIUS Curve GLIDERIGHT Articulation and LogiLock Tibial Base shown above on the Attune PS Knee.

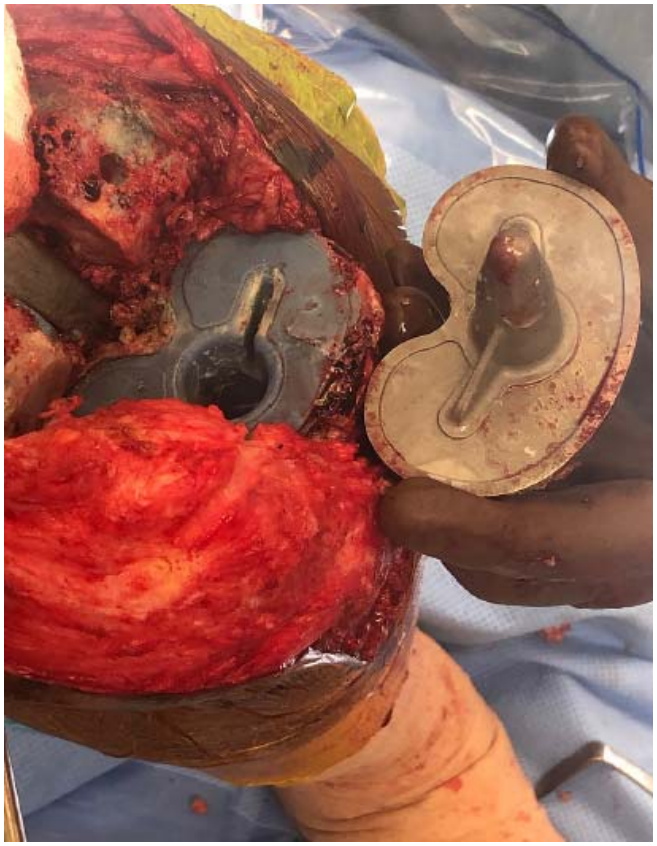


Figure 13: Image from literature (Murphy et al[1]) depicting a debonding failure similar to Julie Sprafka. The intraoperative photograph of a right knee demonstrating cement mantel interdigitated to the proximal tibial surface without adherence to the undersurface of the Attune tibial baseplate.

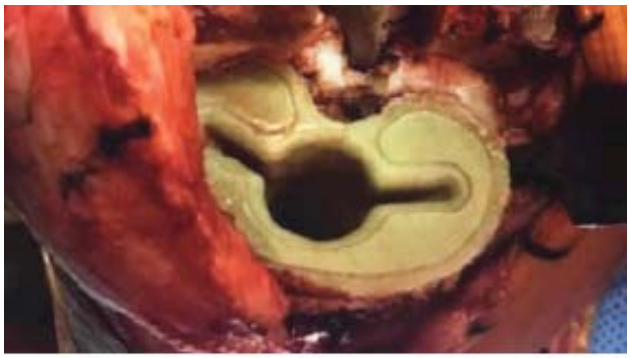
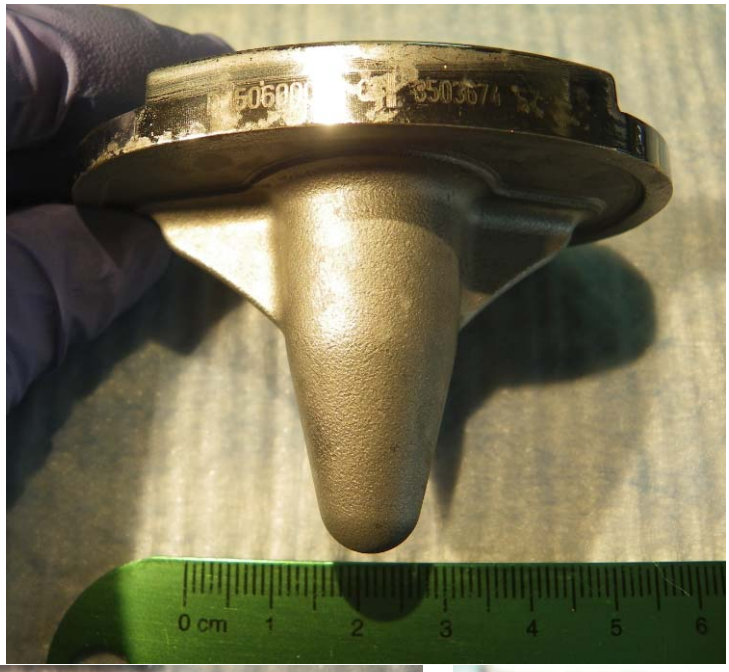


Figure 14: Image from literature (Bonutti et al[2]) depicting a debonding failure similar to Julie Sprafka. The intraoperative photograph of a right knee showing an intact cement mantel adherent to the proximal tibial surface without adherence to the undersurface of the Attune tibial baseplate.



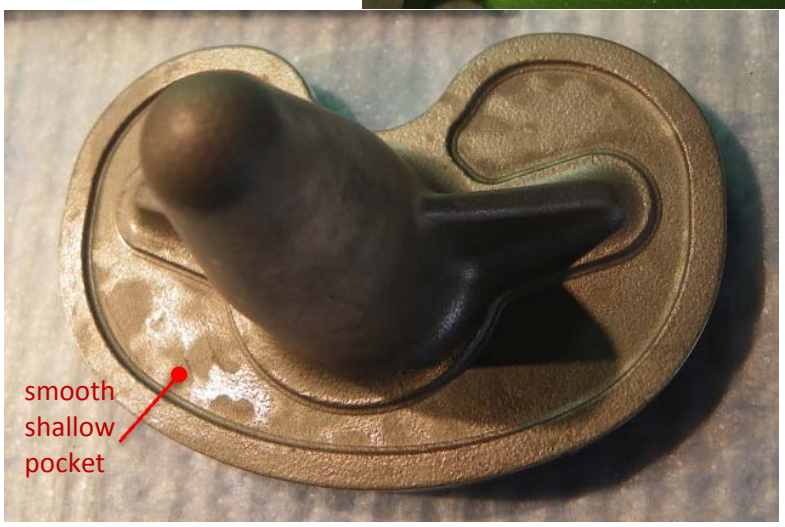


Figure 15: Photographs of an explanted size 3 Attune tibial baseplate, which I inspected (from another patient). The bone cement used in that patient was Zimmer Palacos R. Macroscopically, there is no appreciable bone cement attached to the undersurface of the tibial baseplate including the stem and keel region. The cement pocket is roughly 0.5 mm deep (below the perimeter). The edges of the pocket are radius'd. This increases part strength but reduces cement resistance to shear. (*The cement interface surface was viewed macroscopically and using a stereoscope*.) In that case the cement also remained adherent to the tibial bone after explanation of tibial component. The production prints for Attune backside and stem specified tumble followed by a 60 grit blast finish with a R_t 7 min.[DEPATT 00219223/242][F]

[F]Prints are in metric units, so R_t 7 µm min is presumed. R_t units are not otherwise specified on the Attune Tibial Baseplate prints. R_t (DIN 4748) is the maximum peak to valley height, which is the vertical distance between the highest peak and lowest peak of the roughness profile R within the overall measuring distance(length measured or lm). In other words, this is the height difference between the highest mountain and lowest valley within the measured range. R_t is generally much higher than R_a. For example, N- Class (Swiss VSM) 7 finish is ~ R_t 7.2 or an R_a of 63 microinches , or R_a of 1.6 µm.). The cement pocket depth was not depicted in the finished level print. It was likely specified and controlled on the raw material casting prints (not provided for review).

F. ANALYSIS – IN SUMMARY

In this case, there is a documented breakdown of the tibial tray implant metal surface and the bone cement. The inspection of the retrieved tray component revealed nearly no visible bone cement patches attached except, perhaps a couple very small and thin shining or dull regions on the tibial baseplate components. According to Julie Sprafka's revising surgeon, Kristoffer M Breien MD , the tibial implant baseplate was loose at the cement-tibial base plate interface and the cement -bone interface remained intact. The cement 'debonded'. This is consistent with the lack of bone cement attachment on the retrieved components.

Other surgeons have reported on patients in whom the cement debonded from the Attune tibial baseplate causing tibial component loosening, pain and debilitation requiring revision surgery.[3,4,5,6,7,8,9,10,11,,12,13] Similarly, several comparative studies have documented a significant increase in worrisome radiolucent lines in early follow up for Attune compared to its predecessor PFC/ PFC Sigma tibial baseplates.[14,15,16]

Staats et al[17] stated:
"… whereas infection is the most common cause for revision in the first 2 years postoperatively the leading cause for long-term revisions is still represented by aseptic loosening. And aseptic revision represents a devastating diagnosis for the patient with the result of poor functional outcome. But the etiology of loosening changes with time. Loosening observed in short-term analyses most likely reflects failure to gain fixation. Loosening reported in later years is often due to loss of fixation, secondary to bone resorption."

"Also in contemporary TKA systems there have been reports of early tibial loosening. The radiographic analysis of radiolucent lines represents an established modality for the prediction of component loosening."

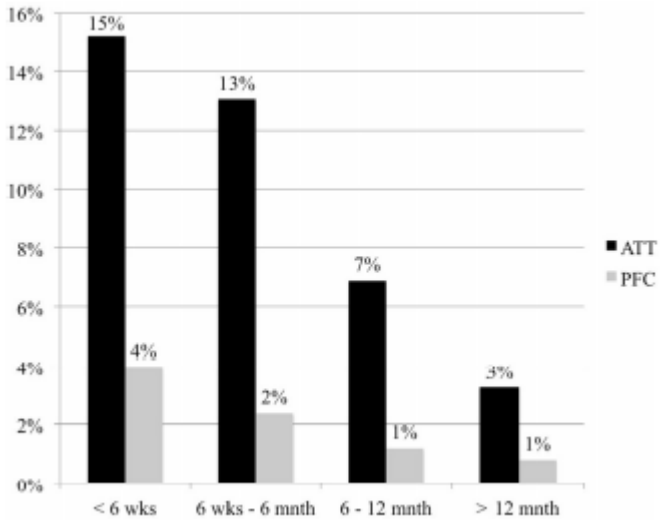


Figure 16: Incidence of radiolucent lines depending on the date of first detection for Attune (ATT) and PFC. In the Attune 40.8% of all radiolucent lines were detectable in the immediate postoperative radiograph (< 6 weeks postoperatively), whereas only 19% (*n* = 4) of all radiolucencies in the PFC-group were visible directly after surgery. In total radiolucent lines were detectable in 37.3% of the ATT-group and in 8.3% of the PFC-group.(Staats et al[18])

Cerquiglini et al [19]stated:

> "The majority of the earliest PFC Sigma designs showed evidence of cement, while all of the retrieved Attune trays and the majority of the RP PFC trays in this study had no cement attached. This may be attributable to the design differences of these implants, in particular in relation to the cement pockets."

Visually the tibial baseplate undersurface lacks macroscopic features to facilitate cement adherence, which is consistent with the report of loosening in Julie Sprafka.

Julie Sprafka's right femoral implant, which is primarily loaded in compression, had substantial PMMA bone cement attached on retrieval. The tibial baseplate, which is subjected to shear /compressive shear, lift-off tensile loading and axial torsion, was void of bone cement. The lack of bone cement on the tibial baseplate component is consistent with lower adhesion strength at the cement-implant interface compared to the bone-cement interface in Julie Sprafka.

My initial visual inspection of explanted Attune tibial baseplates (and the right knee tibial baseplate in this matter) has revealed a relatively a shallow cement pocket retention lip which was rounded and thus unlikely to provide a macro mechanical interlock with bone cement smooth surfaces (where cement would have been applied) on the tibial base plate. The tibial implant is heavy given the volume, consistent with a CoCr Mo alloy. A CoCr Mo was specified to have been used on tibial baseplate. The surface texture appeared macroscopically to be similar to a moderate grit blast on CoCr. There are no mechanical cement capture features such as undercut or dovetails or other 3D structure to capture the bone cement.

In the Design History File, a justification provided for the specified surface finish and mechanical capture mechanism was a desire to weaken the fixation compared to the MTB predicate device to prevent bone loss during revision. However, the design team was warned of introduction of a new risk of inadequate cement adhesion under physiologically relevant higher demand use situations involving A/P shear and torsion such as stair descent.

It was also noted by a surgeon advisor to DePuy [DEPATT 000127866/868] [DEPATT_00128173/175] [DEPATT_00131228/230] that a predecessor Titanium alloy Sigma, baseplate geometry and finish combination had a good cement fixation history. The cement capture feature and surface finish the PFC product family varied somewhat over time.

For example a 2006 web page for the J&J PFC Sigma[G] stated:

> "Tibial component
> Tibial trays are keeled and modular, offered in porous coated and cemented options."
>
> "Cemented tibial components have undercut medial and lateral cement pockets to enhance pressurization and produce a peripheral implant to cement interlock. This seals the fixation interface and protects it from particulate debris. The cruciform keel design assures optimal rotational stability and avoids anterior rocking force. The porous coated option has extensive Coating to the fixation interface, but none to the keel."

Figure 17: Image of one style DePuy Sigma Tibial Baseplate.

[G] http://www.jnjgateway.com/home.jhtml?loc=GBENG&page=viewContent&contentId=0... 10/26/2006

The trays in the PFC product family were historically manufactured from a Ti6Al4V alloy[20], followed later by CoCr alloy in at least some of the Sigma versions. Based on my knowledge of the PFC product history and my review of the Attune tibial it is apparent that the Attune product did not have the same cement attachment features found in the PFC or later PFC Sigma product family. It does not have undercuts or peripheral capture to contain cement.

The tray fixation strength under more realistic static and cyclic fatigue loading should have been investigated by DePuy, and was not. Had DePuy competed cementation simulating intraoperative conditions followed by assessment of cement interface strength under shear, pull off and in vivo cyclic loading they would have identified the debonding risk inherent in their device and then should have adjusted the implant design and surgical technique instructions to mitigate the risk of the Attune CoCr tray-cement mantle debonding which occurred in Julie Sprafka and others.

My review of the design history file, promotional materials and surgical technique guides for the Attune system show that considerable thought or effort was directed toward optimization of the implant design (metal component thickness/strength balance, anatomic fit, kinematics/kinetics and even wear optimization via an anti-oxidant highly crosslinked UHMWPe liner offering). However cement - fixation was not optimized. The design history documentation indicates that the undersurface cement fixation interface was intentionally weakened compared to a successful cemented predecessors, without pre-clinical verification that the reduced strength would be sufficient for the intended use.

The implant was intended for cement fixation, but no effort to assure adequate fixation strength or to optimize the interface fixation strength was done prior to launch of the Attune baseplate in ~ 2011. Nor were adequate fixation features evident upon my visual inspection of explants.

My assessment is that the cement interface surfaces are defective in design and that DePuy could have made minor adjustments to the design to provide interlocking surface features, which would have at least doubled the adherence strength of the metal-cement interfaces, and thereby significantly reduced the risk of debonding of the cement mantle from Ms Sprafka's knee implants. Furthermore, these remedies were well known in the industry well in advance of the development of the Attune TKA system.

The design alternatives include geometry changes to provide macro-lock fixation at the cement-metal interface such a combination of the following:

(1) Deepening the cement pockets and providing a flat wall to contain the cement;
(2) Increasing the cement pocket surface area;
(3) Provision of undercuts such as a key seat or dovetail features the cement pockets;

And

(4) Apply a 3D surface texture to the surface via
- a plasma spray coating[H]
- porous coatings such as sintered beads

[H] Ti , Ti alloy or CoCr

- apply a 3D surface texture to the surface via additive manufacturing processing or sintering processing or Ti or Ti alloy plasma spray coating
- roughen all cement attachment surfaces to an Ra in the range $\geq$ 12.5 μm or

Reasonable alternatives incorporating one or more of these options are available from other manufacturers.

Furthermore, a reasonable manufacturer would have, and DePuy should have, evaluated the risk of cement debonding from the tibial base-plates and the femoral components and characterized the cement adhesion properties of this implant under reasonably foreseeable physiologically relevant load and environment conditions. At the very least static and preferably dynamic loading during development should have been done to assess the comparative adhesion properties to known successful devices to assure that this tibial implant had sufficient cement adhesion under compressive shear, torsion and lift-off (tensile rocking load) conditions. At this time, there is no specific ASTM or ISO consensus standard for this core implant property, but the implant manufacture still has responsibility to assure that the device will function as intended. Among other things ASTM F2083-12 Standard Specification for Knee Replacement Prosthesis states:

> *"6.2 Component Function*-Each component for knee arthroplasty is expected to function as intended when manufactured in accordance with good manufacturing practices and to the requirements of this specification. The components shall be capable of withstanding static and dynamic physiologic loads for the intended use and environment without compromise to their function."
>
> "X2.2 … To date, a majority of knee prosthesis components have been implanted using a bone bonding agent, such as acrylic bone cement in accordance with Specification F451. Although the bone bonding agent is not considered part of the knee prosthesis, it may play an important role in the performance of the prosthesis and, therefore, should be considered during testing and evaluation."

Cement technique instructions should have been formulated for the Attune design in consideration of its cement adhesion capabilities and considering information available in the literature.[21,22,23] For an example see the brochures and surgical techniques more recently provided by Zimmer Biomet[24] and by DePuy-Synthes for Attune.[2526]

An early surgical technique reviewed did not include cementation bone preparation or cement application steps. [DEPATT 00218477/505]

The original technique [DEPATT_00134126; 188] did mention that the cement selected should reach working phase quickly to counter effects of blood lamination (fluid pressure). Among other things, it did not address cement mixing , use of vacuum, cement application tools, application of cement first to the metallic implant surfaces while the cement is in the 'sticky' phase (maximum adherence range). Cementation technique also did not encourage or suggest application of cement on both the implant and bone to maximize fixation strength or the need to pressurization of the cement to assure adequate infiltration.

E. ANALYSIS – IN DETAIL

Background

Bone cement acts as a grout by filling in the voids that are left between the implant and the patient's bone, thus creating a mechanical interlock. This is why the role of the cement is directly related to its mechanical properties, especially its resistance to fracture in the mantle at the cement-prosthesis interface or the cement-bone interface. The use of acrylic bone cements present disadvantages including high polymerization temperature, neurotoxicity of the monomer and lack of osteointegration due to their bioinert nature, i.e., it does not resorb or allow bone replacement. It is therefore encapsulated by fibrous tissue causing instability and movements at the bone cement-prosthesis interfaces, which are considered the weak-link-zones. These micromovements can accelerate aseptic loosening, causing a failure in the cemented TJR.

The primary roles of bone cement in arthroplasty are immediate fixation of the implant to the bone and force transfer from the implant to the surrounding tissue. In order to adequately perform these functions, bone cement must be compatible with the host tissue as well as possess sufficient strength to withstand the large and repetitive magnitudes of load/stress to which it is exposed. Mechanical properties of bone cement play an essential role in the long-term outcome of a cemented joint arthroplasty. Typically, acrylic bone cement is a two-component based formulation: a solid phase of PMMA, a radiopaque agent and an initiator; and a liquid phase of methyl methacrylate (MMA) with an amine as co-initiator and hydroquinone to inhibit autopolymerization. Due to its radiolucent nature, a radiopaque substance is added to the formulation in order to monitor the bone healing process. This modification allows the identification of osteolytic lesions around an implant and the detection of fractures within the bone cement after surgery, using fluoroscopic or X-ray control. These fillers, or radiopacifiers, typically dense metal powders, affect the energy attenuation of photons in an X-ray beam as it passes through the material, thus reducing the intensity of the photons by absorbing or deflecting them. As these materials exhibit higher attenuation coefficient than soft tissue or bone, they appear lighter shadow on a fluoroscope or X-ray film. Most commonly used radiopaque particles are barium sulphate ($BaS0_4$) and zirconium oxide ($Zr0_2$) but, as they are highly polar, phase separation is observed due to their incompatibility with low polar polymer matrix, leading to degradation of physical and mechanical properties of the cement.

Bone cement initially used by Dr Charley in 1960 for total hip arthroplasty and gave excellent clinical results with good preservation of long-term joint function. Subsequently, replacement arthroplasty with an artificial joint has become the standard and most reliable operative treatment for osteoarthritis of the hip and knee. However, aseptic loosening with destruction of the bone (osteolysis) near the implant occurred in some cases even after a long period of good function. This was found to be related to reactions to implant wear debris, primarily from polyethylene and PMMA.

Tissue response around prosthesis results in either formation of a fibrous layer around the implant, ingrowth into fenestrations on implant or direct bone apposition on prosthesis. Long-term implantation results in implant debris being released into surrounding tissue. These particles initiate a chronic granulonatous inflammation with a significant number of activated macrophages and foreign body type of giant cells, all engaged in attempts to get rid of the

debris. These features have been found to be invariably associated with peri-prosthetic lysis of bone. Since such bone resorption is also observed around non-cemented prosthesis, possibly causes other than cement are responsible for the osteolysis. Retrospective studies on failed implants suggest that peri-prosthetic osteolysis is mediated by activated macrophages. Cytokines are capable of stimulating bone resorbing cells, the osteoclasts. Bone resorption results in further loosening of the prosthesis, changes in stress, frictional wear, release of more wear debris and recruitment of more macrophages. Bone death and proliferation of macrophages, thus appear to be the cause for pain and loosening of prosthesis.

However, long term aseptic loosening still occurs and remains a problem to be over- come. The primary sources of wear debris are polyethylene wear and wear due to cement breakdown.

Improved polyethylene (*e.g. consistent mechanical properties, processed to minimize residual free-radicals, moderately to highly crosslinked, and some include stabilizers such as vitamin E*) and articular surface interface designs have great reduced the polyethylene wear debris.

Cement Breakdown

Cement breakdown results from overload of the bone-cement or the cement-implant interfaces in-vivo. While the manufacturer and the surgeon cannot intra-operatively change the patient's bone quality, they can influence the outcome by following state-of-the-art design, manufacturing and installation techniques. The manufacturer has a duty to characterize the *expected performance* of their devices using a combination of in-vitro pre-clinical empirical testing and finite element analyses (FEA).

The surgeon can minimize the risk of cement overload by aligning the implant appropriately, by using modern cementing techniques, and by balancing the soft tissues. For example the tray needs to extend over the cortical perimeter, so the surgeon needs to select the best fit size.

Among other things, manufacturers need to:

- Supply a sufficient number of shapes and sizes to assure cortical bone coverage without excessive overhang which can damage or irritate soft tissues;
- Supply implant bone cement surfaces which are conducive to cement adhesion and yet resistant to fatigue cracking and debonding;
- Supply appropriate central stem options to assure load transfer under foreseeable load conditions;
- Characterize the *expected performance* of their devices, and communicate the limitations of their device to surgeons in a manner that allows them to make informed choices concerning (a) the appropriate implants for specific patients; (b) appropriate cementing techniques; and (c) activity restrictions based on the implant capabilities, as applicable.

As with all cyclically loaded systems improving retention stability and reducing debonding tendency means reducing crack, void and flaw frequencies in the interfaces of TKA/bone cement/bone. Cracks originating at the interface metal/bone cement may also influence stability at the interface bone cement/bone, since due to subcritical crack growth promoted by static and in particular due to cyclic loading cracks starting at the interface metal/bone cement

can extent to the interface bone cement/bone. Since in vivo conditions of the human body (37°C, 100% humidity) strongly favor hydrolysis, and due to the strong interaction of the metal oxide layer of the metal surface of the TKA with polar water molecules, the bone cement/ metal interface is prone to hydrolysis. The water causes hydrolytic degradation of the metal/bone cement interface, when it is not conditioned to this environment. The water molecules diffuse through the permeable PMMA and easily reach the interface to form a moisture film at the metal-cement interface even when the PMMA layer and the interface are free of cracks. Any cracks or fissures will accelerate the process via capillary action. Thus, the initially solid bond between the oxide layer of the metal surface and the bone cement is eroded and becomes mechanically unstable as the metal-cement interface is progressively hydrolyzed. [27] Mechanical degradation in combination with hydrolytic load of the interface metallic tibial surface/bone cement is an important failure mechanism for aseptic loosening of surface cemented tibial prosthesis components. The bond strength between bone cement and unconditioned samples of CoCrMo is unstable against hydrolysis and stability, which is provided by surface roughness alone, is insufficient.[28]

Documented Strength of Metal-PMMA Bone Cement Interfaces

Bone cement is strongest in compression and weakest in shear and tension. Shear and tensile forces occur at the tibial baseplate-cement interface. Per ISO 5833 the compressive strength limit of PMMA cement must be ≥ 70 MPa and the bending strength ≥50 MPa. As an example, Kuhn reported the ISO mechanical properties of Palacos R to be in the range of 76.3 to 89.2 MPa depending on the power/liquid mix ratio. Mechanical properties including fatigue behavior of various commercial cements can be found in are Kuhn chapters 12-14.[29]

The tensile strength of conventional bone cement is 25–35 MPa[30] , so tensile bond strengths greater than 35 MPa cannot be achieved using standard self-curing PMMA bone cement.[31] The shear strengths per ASTM D732 are in the range of 32 to 62 MPa for hand mixing vs vacuum mixing. [32] Methyl methacrylate (MMA) itself is not adhesive to metals and attachment to metal is primarily obtained by mechanical retention.[33] Furthermore it was well known in the industry by the early 1990s that by far the best cement –metal interface strength occurs where the metal had a 3D porous structure such as the porous bead or titanium mesh utilized for bone ingrowth (~18 to 25 MPa). The next best included a 2D surface texture like Ti or Ti alloy plasma spray (~ 7 to 10 MPa), followed by large grit blasted surface mesh size ~12, 16, 20 or perhaps 24[I]). Specific example from the literature follow.

Thus it has been well known since the 1980s and 1990s that tensile and shear strength between bone cement and the metal tray or stem on a tibial baseplate can be improved by making the surface irregular & rougher. It was common to have cement pockets that were at least 1 mm deep and some designs had undercuts or dovetail features to physically capture the cement. Most knee implants with 3D beaded or fiber mesh porous coatings were cleared for used with cement and it was well known that the cement –implant interface was strongest when the metal interface had a 3D porous texture.

While the main method for improving metal/bone cement interfaces is through changing surface topography , several have shown that the interfaces can be substantially strengthened

[I] Smaller mesh number equates to larger grit size and a rougher implant surface texture.

by applying the bone cement to the metal with high pressure. This was also well known by the 1990s. High pressurization is practical for precoated implants, but not use in the operative theater where the method involves low pressurization.

Implant contamination such as saline, bone marrow and blood prior to cement application has the potential to affect the cement-implant bond. During intraoperative use air and other contaminants can be trapped at the interface between cement and implant metal, and more contamination occurs when the metal surface is rough thereby weakening the tensile bond strength.[34] Lipids/marrow are major intraoperative contaminants that can reduce cement and cement –metal interface fixation strength.[35] Even so, roughened surfaces have improved bond strength compared to smooth. Contamination at the metal interface can be avoided using high pressure pre-coat applied under controlled conditions. Stone et al [36] (1989) documented cement-metal interfaces as high as about 14 MPa for precoated stems (mean 12 MPa) under dry conditions without contamination. Contamination during a TKA reduced the interface shear strength to 4 or 5 MPa. (Palacos R) Wang et al[37] (2013) documented a significant reduction in interface strength given each contaminant. Contaminants largely decreased stem-cement interfacial shear strength, especially for rough surfaces. Saline produced the greatest decrease, followed by blood. The effect of bone marrow was less pronounced and similar to that of oil. Increasing surface roughness increased the interfacial bonding strength, even with contaminants. SEM results suggested that contaminants such as saline and blood form a layer on the metal-cement interface and reduce the amount of mechanical interlock; other contaminants such as bone marrow and oil produced unusual features suggesting the influence of more complex lipid-monomer interaction.

There have been several reports on the push-out or pull -off strength of the metal-cement interface.

Raab et al[38] (1981) documented the degradative effect of a physiologic fluid environment on the cement-metal interface adhesion strength. The quasistatic interface strength for a CoCr-cement interface reduced from 6.9 MPa to 5.3 MPa after 30 and 60 days in saline, while the interface strength for Ti6Al4V reduced from 12.5 MPa to 6.3 to 6.7 MPa at 30 and 60 days. These authors noted that the high polarity of the water molecules, that is their capability for hydrogen bonding with metal oxides, precludes the effectiveness of any of the weak secondary interactions with which PMMA would bond to a metal oxide or polyethylene surface. **Thus it was known in 1981 that it was critical to consider macro mechanical features, such as 3D porous structures and pocket with undercuts or dovetails to contain the PMMA and provide mechanical interlock due to the weak interface strength, which degrades in the in vivo fluid environmen**t. Using static tests. Raab et al[39] (1982) also documented that precoating the metal stem with a thin layer of PMMA significantly increased the static strength of the cement-metal interface.

Cook et al[40] (1987) found that coating cylindrical specimens with metal beads create a porous surface significantly increased the static pushout strength of the cement-metal interface over non-porous coated specimens. They also found that the cement-porous metal interfacial shear strength increased with increasing pore size.

> "The noncoated metal specimens displayed interface shear strength of 4.2 +/- 0.4 MPa, whereas the shear strengths for the porous-coated specimens were significantly higher

and increased as pore size increased. The mean interface shear strengths determined were 17.0 +/- 2.1 MPa (165 microns pore size), 18.1 +/- 2.3 MPa (285 micron pore size), 23.6 +/- 1.7 MPa (345 microns pore size), and 25.4 +/- 3.4 MPa (550 microns pore size). Significant differences in shear strength for the porous-coated specimens were found between the two smaller particle sizes and the two larger particle sizes. As pore size increased from 285 microns to 345 microns, a statistically significant increase in shear strength from 18.1 MPa to 23.6 MPa was observed."

Bundy et a[41] (1987) performed static torsion tests on the cement-metal interface and concluded that interfacial shear strength was found coarsest and the finest surface finishes compared to the intermediate finish. Highly polished surfaces also improve interface strength (compared to less polished surfaces). The hypothesis is advanced that adherence depends upon superposition of mechanical interlocking and atomic interaction effects. Like others, they also found that porous metal surfaces formed an interface with bone cement that had very high shear strength.

Davies et al[42] documented that a metal with a thin film of PMMA precoated also significantly increased the number of compressive fatigue loading cycles required for failure of the cement-metal interface under cyclic loading compared to a smooth, uncoated surface. Adding indentations to the surface and then precoating with PMMA further significantly increased the fatigue life of the cement-metal interface. The strongest interface in fatigue was the titanium fibermesh-cement interface. **The fatigue strength of the cement-metal interface was 1-3 MPa, compared to 7 MPa for bulk cement.** [43] Rabb et al[44] (1982) used rotating bending tests at 20 Hz to characterize the fatigue properties of the cement-metal interface.

Using surface finishes common on TJR implants, Crowninshield et al[45] (1998) reported the push out forces of CoCr (ASTM F799) metal plugs from PMMA based on surface finish. Under their quasi-static loading mode rougher surfaces had the greater push-out force. The mean surface finish range evaluated was from Ra 0.10 to 6.33. Note that other processes such as a more aggressive grit blast or plasma spray coating can achieve greater surface roughness (Table 2). There is a general increase in bone cement attachment strength with increased metal surface roughness.

Table 1: Surface Roughness Data for the Push Out CoCr Rods Used in Cement on Metal Adhesion Testing[46]

Surface finish	Average Ra (μm)	Average Rz (μm)	Average Push out force (N)	Average Push out force (lb)*
mirror like polish	0.10	1.54	191	42.94
mass tumble	0.31	2.62	244	54.85
glass bead blast	0.26	1.92	569	127.92
400 grit belt polish	0.71	5.39	1459	328.00
60-grit alumina + glass bead blast	1.43	9.52	2269	510.09
60-grit alumina blast	1.91	13.29	4169	937.23
24-grit alumina blast	2.88	17.63	4312	969.38
16-grit alumina blast	6.33	34.60	9936	2233.70

*Plug lengths and diameters were not reported in this article. These test samples were dry prepared, cured and tested . Thus, the push out specimens results represent the best-case

interface condition and depict higher absolute push out strength when compared to in vivo conditions, Zimmer has sold PMMA precoated hip and knee implants for several years, and others have developed similar processes[47]. Precoat processing alone has not assured a durable implant-cement interface[48,49]. As noted in many studies, surface finish[50] and implant design features also effect interface stresses and thereby adhesion under in vivo load conditions.

Table 2. Definitions of Metal Implant Surface Appearance and Typical Methods of Manufacturing in R_a and R_z.[51]

Surface Appearance	Typical Manufacturing Methods	Approximate Roughness Range R_a (µ inch/µm)	Approximate Roughness Range R_z (µ inch/µm)
Shiny	Polishing	0–5/0–0.1	0–75/0–2.0
Smooth	Machining, grinding, mass finishing	5–15/0.1–0.4	75–150/2.0–4.0
Satin	Bead blasting, machining	15–40/0.4–1.0	150–250/4.0–6.0
Matte	Grit blasting, combination grit + bead blasting	40–100/1.0–2.5	250–750/6.0–20
Rough	Aggressive grit blasting, plasma spraying, sintering	100–500/2.5–12.5	750–2500/20–60
Textured	Machining, casting, forging	500+/12.5+	2500+/60+

While DePuy did not specify macroscopic cement capture features on the tibial baseplate implanted in Julie Sprafka, such as undercuts, they did specify a surface texture in what is considered the rough to low textured range, specifying a 60 grit alumina oxide blast with a minimum total roughness depth (R_t) of 7µm. [DEPATT_00131791], but an Ra in the range of 2.5 to 3.5 µm. [DSUS/JRC/0517/2142(1) 08/2017 pg 66]

A cemented femoral component's surface finish may influence implant function through variations in cement adhesion and abrasion properties. Loading and fixation interface shape varies for total hip arthroplasty (THA) vs TKA. In THA , when PMMA is placed between bone and implant, bone cement can function as an interpositional material and provide implant fixation without reliance on adhesion of the bone cement to the metal implant surface. Without adhesion interface motion is likely and abrasion must be considered. It is important to note that smoother implant surfaces have lower cement-metal interface fixation strength, whereas rougher surfaces have greater fixation strength. With interface motion, the smoother surfaces are less abrasive of bone cement, whereas rougher implant surfaces are more abrasive.

The predominant forces acting on the femoral stem–cement interface in THA are shear, whereas the tibial baseplate–bone cement interface fluctuating forces are compression, tension, torsion and compressive shear, depending on the activities undertaken. It is also known that the cement mantle in a cemented total knee arthroplasty experiences fluctuating loads. (Refer to **Appendix B** - Forces on the Implanted Knee.) These are forseeable conditions to be be considered by the implant manufacturer. DePuy was aware of the forces on the TKR. DePuy, in part, modeled physiologically relevant loading in its kinematic analyses/physical simulations (Kansas knee simulator) and in its stress analyses for the Attune patello- femoral [DEPATT_00131576/598, 640/667, 668/674, 676/683] and tibio-femoral interfaces [DEPATT_00132190/214 ,225/244].

While DePuy completed many analyses of the effects of physiologic forces on the Attune knee implant patello-femroal and tibio-femoral joints during development, I did not see stress

analyses or static or dynamic testing to assess the effect of these more complex and physiologically relevant combined forces on the tibial baseplate-cement interface. The testing DePuy compelted was limited ot simplistic pull off for the impant - cemtn interface fixation strenght assessment.

I did not specifically see dynamic testing of tibial implant cement bond in the validation cadaver lab evaluations or in the in-vitro testing. [DEPATT 127671 - 127933].

Attune validation plans did not include evaluation cementation technique including cement - bone or cement implant interface strength. [DEPATT 128053/61; 62/74]

In the 2007-2008 time frame during development of Attune, DePuy asked its surgeon design team to review/select/approve use of a a new surface finish texture (60- grit blast) on the cemented tibial baseplate and the cemented femoral AP box which had inferior cement fixation properties (in pull off testing) compared to its own clinically successful predicate device, the MBT. DePuy represented that this finish had not been used on prior implants. The design of the baseplate undersurface geometry (shallow pockets without undercuts) was established and the design frozen by DePuy prior to selection of the surface finish.

At various times the surgeon advisory team had recommended use of the MBT finish on at least the undersurface if not the keel and stem surface of the tibial baseplate because the MTB had a successful clinical history. Based on my experience as an engineer in the industry, masking can be applied to implant zones prior to blasting to generate different surface textures in different regions of the implant with only a slight cost increase due to the masking and subsequent cleaning. However, this option was rejected due to this slight cost increase.

At least two surgeon-advisors had recommended that if a new surface finish was adopted to us eon the established geometry (which had shallow pockets and no undercuts or other geometry to mechanically interdigitate with the cement) , then fixation interface durability utilizing more physiologically relevant rocking, tilting and shear was in order. I have seen no evidence that DePuy conducted the more complex testing involving rocking, tilting and shear. DePuy chose to limit fixation testing to a simplistic axial pull-off characterization with low clinical relevance.

Refer to Appendix C **Selected Team Discussion - Tibial Baseplate Finish** for Team discussion points in the 2007-2008 time frame when the surface finish and tibial baseplate undersurface geometry was established.

In tibial baseplate applications attachment to and frictional traction at the metal surface is required to provide implant stability.

Historical Background, Bone Cement Adhesion/Bonding to Metallic Implant Surfaces

Davies et al[52] examined the effect of a smooth 'implant finish' surface, a PMMA precoated surface, a combination of a textured surface with PMMA precoat, and a porous titanium mesh coated surface in a cyclic fatigue test. Precoating the metal with a thin film of PMMA significantly increased the number of compressive fatigue loading cycles required for failure of the cement-metal interface under cyclic loading compared to a smooth, uncoated surface.

Adding indentations to the surface and then precoating with PMMA further significantly increased the fatigue life of the cement-metal interface. The strongest interface in fatigue was the titanium fibermesh-cement interface.[53] In this work the samples were soaked in a 37°C water bath for at least 7 days prior to testing. The specimens coated with titanium fibermesh produced the strongest cement-metal interface tested in this study, endure over 5 million cycles (testing stopped) where the typical implant textured surface failed at less the 30,000 cycles, and the precoated between 60 and 1 million cycles. Davies and Harris recorded an average tensile strength of 5.3 MPa for standard grit-blasted cobalt-chrome samples (Ra = 1-2 μm) after curing the cemented samples in saline at 37°C for 18 hours.

More recently (2006) Pittman et al[54] studied the tensile and torsional strength of the cement –tibial component in surface textures that represented textures found on more contemporary TKA using Palacos R polymethyl methacrylate (Biomet Inc) and both Ti6Al4V (ASTM F136) and CoCr (ASTM F75) alloy cylinders. Their results indicated that, in general, metal-cement tensile interface strength increases with increasing surface roughness and common surface treatments such as AlO_2 grit-blasting (Ra = 6.76 microm) produce interface strengths lower than but close to plasma-spray, porous-coated specimens.

Table 3. Average Surface Roughness of Each Tibial Component Sample Subgroup

Surface finish	Material	Ra (μm)
Porous-coated	Titanium	20.4
	Cobalt-chrome	20.4
30 Grit AlO_2 GB	Titanium	6.76
	Cobalt-chrome	6.76
Macrosurfaced	Titanium	NA
	Cobalt-chrome	NA
Ceramic GB	Titanium	0.973
	Cobalt-chrome	0.973

GB indicates grit-blasted; NA, not applicable.

It should be noted that, as an alternative, modern production processes (sintering, vacuum plasma spray, additive manufacturing, are capable of generating more textured surfaces with high shear and pull off strength including many 3D coatings with only moderate reductions in metal fatigue strength. Such coatings are able to interlock cement.

The tensile strength ranged from 2.7 MPa (Ceramic glass bead) to 10.3 MPa (Plasma spray porous coating). The AlO_2 grit–blasted samples failed at the prosthetic-cement interface without fracture through the cement. This is one of the most common surface coatings used in more recent cemented tibial baseplates. ***This testing was completed in a dry environment with no soaking of the interfaces.***

When compare this to the shear interface strength reported by Raab et a1[55], the 4.2 MPa for non-porous coated surfaces is somewhat lower but the range of 18.1 MPa to 25.4 MPa shear strength reported for 3D porous structures is significantly greater.

The type of metal substrate and surface preparation of contemporary tibial baseplates influence the strength of the metal-cement interface and as such influence tibial component survival. In general, metal-cement interface strength increases with increasing surface roughness and common surface treatments such as larger AlO_2 grit-blasting (Ra = 6.76 μm or 236 μinch *or greater*) can produce interface strengths similar to plasma-spray porous-coated specimens in titanium alloy devices (vs CoCr devices), but not as high as other macro textures (20 μm or 787 μinch *or greater*). Plasma coating is a relatively inexpensive process and has the benefit of a minimal effect on the fatigue strength of the tibial tray when compared to sintered porous coatings.

A specific type of waffle macro surfaced tibial baseplate surface, although comparable in tension, was more vulnerable to metal-cement interface failure with rotational loading. This waffle surface texture is not found on many current tibial implants. Macro surfaced tibial components(waffle patterns), although comparable in tension, may be vulnerable to metal-cement interface failure with rotational loading.[56]

Grupp et al[57] reviewed the literature relative to in vitro testing of tibial fixation:

> " Several studies had been undertaken to examine the influence of implant design, bone fixation principle, surface structure and cementing technique on the primary stability of uni- or bicompartmental tibial implants in vitro and in vivo. To evaluate the primary stability of tibial plateaus, in vitro, in silico and ex vivo approaches had been undergone: cement penetration depth analysis in the proximal tibia (Maistrelli et al., 1995; Clarius et al., 2012), finite element analysis (FEA) to assess resulting bone stresses and strains (Completo et al., 2008; Kelly 2012; Cawley et al., 2012), static tension (Schlegel et al., 2011; Gebert de Uhlenbrock et al., 2012) or compression loading (Clarius et al., 2010; Completo et al., 2012; Jaeger et al., 2014) until interface failure. However, these test conditions do not reflect the in vivo physiologic loading modes, where the tibial plateau is predominantly subjected to combined compression and shear forces in a cyclic profile (Zhao et al., 2007; Kutzner et al., 2010; Bergmann et al., 2010; Grupp et al. 2013)."

The authors made a reasonable case that the primary stability of a TKA tibial plateau should be assessed under dynamic compression shear loading conditions in human tibiae. Using matched pairs of cadaver tibias Grupp et al[58] studied full and surface cementation of a tibial tray with a keel and varying stem lengths on the primary (initial) stability of a posterior stabilized tibial plateau. The authors did however conclude that there is no significant difference between a 40 mm and a 28 mm tibial keel length in the effect on the primary stability of surface cemented tibial plateaus, in terms of failure load, migration characteristics and cement layer thickness including the penetration into the trabecular bone. In addition the authors did not feel that there was a substantial benefit of a full cementation versus a surface cementation) on the primary stability of a posterior stabilized tibial plateau, in terms of failure load, migration characteristics and cement layer thickness under dynamic compression-shear loading conditions in human tibiae. Since this testing was short term and did not include a full regime of physiologic motion, the in vivo fatigue performance was not fully accessed by this study. (This work did not address cement-tray debonding issues but rather tray stability in the bone. under uni-axial loading. The effect of varying ML and AP loading and lift-off tension was not evaluated.)

The cement-implant fixation shear strength is greatest with larger porosity (165 to 550 microns, 17 to 25 MPa[59]) followed by plasma sprayed surfaces (10.3 MPa[60]) followed by rough blast surfaces (4.2[61], to 6.25[62] MPa) followed by smooth (fin ceramic blast or even polished) finishes (0.973[63] to 4 MPa [64] ***The Plasma spray , grit blast values represent best case strength at day 1, prior to soaking in the in-vivo fluid environment. It has been shown that the shear strength decreases in a wet environment*** [65, 66] Raab et al[67] documented that after 30 and 60 days exposure to saline the shear strength was only 53% of the original for Ti6Al4V-PMMA interface and only 76% for the CoCr-PMMA interface (a 47% and 24% loss respectively). For comparison purposes, researchers have identified a maximum shear strength range of 15-17 MPa for porous

implant bone interfaces.[68] Without macro locking features their remains a risk of cement-implant interface debonding.

Thus, it has long been known in the orthopaedic community that a 3D macro lock is needed to assure equivalent metal-PMMA interface durability under in-vivo conditions. Cement interfaces, which were common on cemented devices in the 1980s and 1990s included:

1. Pockets (1 to 2 mm deep) with a substantial flat edge region capable of converting some of the shear loading to compression (*not simply radius'd edges as seen on the shallow pockets on the Attune Tibial base-plate*) combined with rough grit blast surfaces (roughness as created by grit blast mesh sizes 12, 16, 20 or 24 Ra in the range of ~3 to 10μm).
2. Pockets (1 to 2 mm deep) with pockets with undercuts or dovetails capable of converting some of the shear and tensile loading to compression combined with rough grit blast surfaces (roughness as created by grit blast mesh sizes 12, 16, 20 or 24 Ra in the range of ~3 to 10μm) .
3. A larger pore porous surface such as titanium mesh or beaded porous coatings or Ti or Ti6Al4V plasma pray coatings.
4. Less common: Waffle surface textures, sometimes combined with rough grit blast texturing (roughness as created by grit blast mesh sizes 12, 16, 20 or 24 Ra in the range of ~3 to 12μm, or at least 60 grit 60-grit alumina or 60 grit glass bead dry blast (surface Ra of .5 to 2 on top of the 3D macro texture)

The first 3 alternatives have a long history of clinical success. The fourth option was shown not to be as durable in in-vitro (laboratory) testing and is not commonly seen.

However, pocket depth have reduced below 1 mm in some modern implants, including these Attune devices, with negative consequences. This may have been done, in part, in an effort to assure sufficient tibial tray fatigue strength while assuring 6 mm of UHMWPe liner thickness and also minimizing the total thickness of the tibial tray (keeping total thickness of the thinnest tibial implant to 8 or 9 mm). The sacrifice is the strength of the implant metal-PMMA interface strength.

The cement pocket depth is shallow in the original Attune knee product. Visual inspection revealed radius'd edges on these shallow pockets. This design offers little resistance to shear forces at the cement-implant interface. Mechanical resistance to shear is implant at this interface because of the poor adhesive properties of bone cement and its weakness in shear.

The pocket depth of the on the tibial baseplate is well below 1 mm. The production print did not specify the height and width of the visible ridge, but using digital calipers, I measured the perimeter ridge height. It measured to be between approximatley 0.50 to 0.60 mm during my visual inspection.

The dimension for the ridge height is not apparent in the base tray prints that I have reviewed in the discovery documentation. (The finished level prints referred to casting level prints, which were not provided.) The dimension for the ridge height (pocket depth) in on the rotating platform trays is not legible, but may be 0.75 mm. *Scaling the drawing image indicates the pocket depth to be roughly 0.62 mm.*

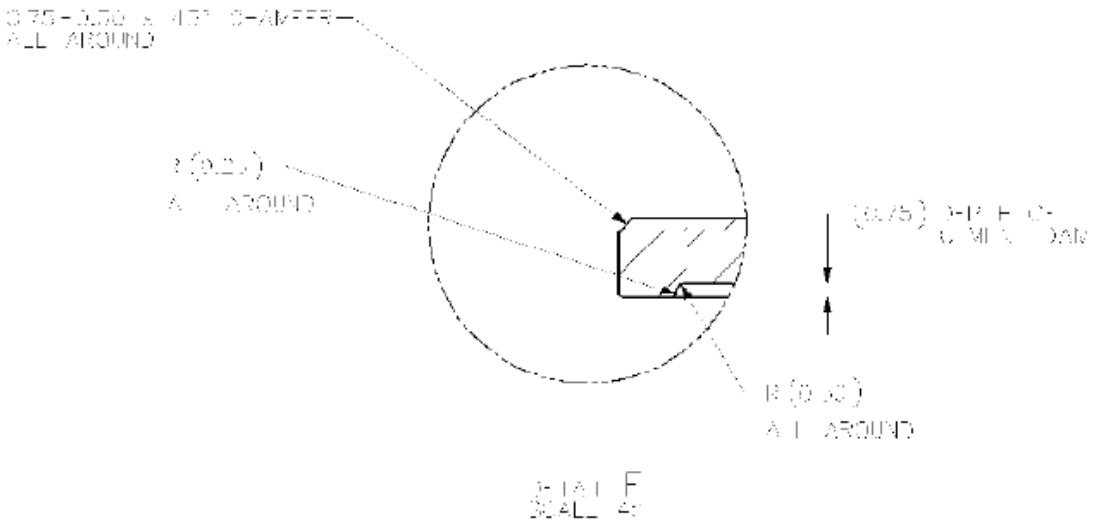


Figure 18: Image showing pocket depth in in a rotating platform bearing tray. [DEPATT_00219278/296]

There are no keyseat undercuts or dovetail undercuts to mechanically capture the cement on the Attune CoCr tibial baseplate used in Julie Sprafka.

DePuy specified a 60 grit blast surface finish with a surface roughness total (R_t) of at least 7 , with a reported R_a equivalent of at least 1.6µm and as high as 2.5 to 3.5µm. Cerquiglini et al[69] documented a surface roughness of Ra 1.24µm on the cement fixation side of a retrieved Attune, which is at the low range expected based on the print specification for R_t.

Testing completed during development documented that the rougher finish created by a 20 grit blast did result in a larger direct pull-off strength compared to a 60 grit finish. [WR090235, DEPATT 00220817, DEPATT_00132112/113]. The interface strength (effectiveness) in more physiologically relevant shear induced due to rocking or tilting moments was not measured. This was discussed in team meetings prior to launch of the Attune. The design if the Attune was finalized prior to full investigation of the cement retention capability of the tibial baseplate design Dan Auger.[DEPATT_00128175]. [DEPATT 00128032/34, DEPATT 127929/930,DEPATT 000127866/868, DEPATT_00128173/175, DEPATT00128196, 202/203, DEPATT 00128207, DEPATT_00131228/230]

Refer to Appendix C for selected notes. The 2008 Design Control Plan, rev D, with an August 1, 2017 creation date, only referenced the simplistic pullout strength comparison test and specified and the design intent was to provide reduced cement-to-baseplate fixation strength (in pull out) for Attune compared to the clinically successful MBT. [DEPATT_00130647] The 2008 Design Control Plan Rev H indicated that the Attune tibia baseplate was intended to have weaker cement to component interface strength. [DEPATT_00130676] This requirement contributed to the design defect and the debonding problems experienced by Attune patient, including Julie Sprafka.

According to Torino et al[70] the underside of the original Attune tibial baseplate was designed with a grit-blasted surface finish roughness of 2.5-3.5 Ra. The implant was redesigned in 2017

introducing a new tibial baseplate, which was reconfigured with an undercut cement pocket area and a greater surface roughness (3.0-6.5 Ra) to enhance cement bonding. The effects of tibial implant debonding on the bone-implant interface which result in pain, loosening and procedure failure are more fully discussed in a literature review entitled "***Literature Review - Tibial Component Debonding in TKA***", which has been attached as **Exhibit 4.** The purpose of the literature review is to discuss the etiologies of peri-prosthetic osteolytic bone resorption below a cemented total knee implant and document evidence of osteolytic processes consistent with early tibial baseplate-cement debonding.

Given that the Attune tibial baseplate had no substantial mechanical capture feature to secure the bone cement, the specification of a 60-grit blast surface finish on the baseplate CoCr cement fixation surface with an R_t of and an R_a equivalent of only ~ 2.5 to 3.5μm is a design defect.

F. RESPONSIBILITIES

Other Manufacturers Provided Safer/More Durable Alternative Designs

Alternative modern TKA devices have deeper pockets with flat walls and rough grit blast surfaces with pre-coated PMMA (Nexgen Legacy as an example) or without precoating such as Biomet AGC or VanGuard and the more recent DePuy Attune S+ tibial trays as examples)

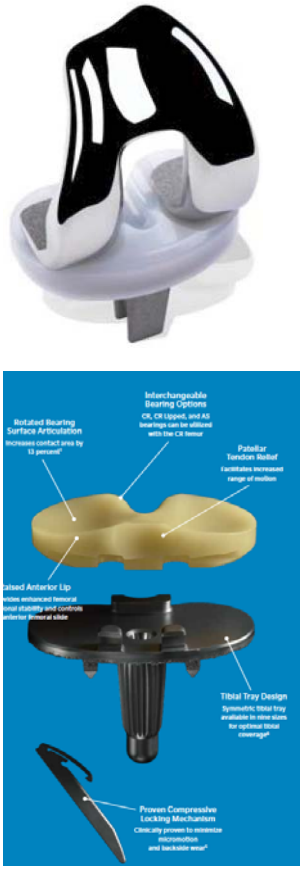


Figure 19: Biomet /Zimmer Biomet TKA components. **Upper left**: AGC cemented tibial tray is shown (*featuring a roughened surface or Interlock finish*). **Upper right**: Vanguard cemented tibial tray is shown. **Lower left**: Regenerex Porous Titanium surface on the tibial tray. Sources: Zimmer Biomet brochure No. BIO0264.2-REV0616; AGC Concise Optec Surgical Technique FLK162-AGC-Concise-optec, www.biomet.co.uk

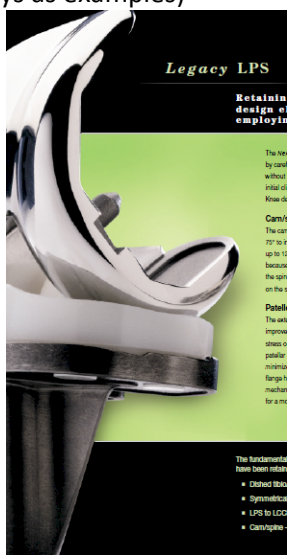


Figure 20: (**Above**) Nexgen Legacy tray with long Keel and cement pockets. Zimmer brochure 97-5970-01 ©2002 Zimmer Inc. Note that many of Zimmer's cemented devices feature a precoat of PMMA.

Many cemented tibial implants in the early 1990s featured cement pockets which were ≥ 1mm in depth. Some pockets features keyseat or dovetail undercuts. Other implant surfaces were covered with plasma spray or porous coatings, or at least a coarse grit blast finish with the coarsest surface being generated using a 12 or 16 mesh grit on a Ti6Al4V surface (Ra ≥ 8-12 microns), and the least rough being generated with a size 24 grit. Keels or spikes in addition to a central stem were common to mitigate shear forces.

Figure 21: Detailed examples of lips and undercuts found in retrieved Attune and PFC Sigma tibial baseplates as reported in Cerquiglini et al[71] . Deeper deeper cement pockets with dovetail undercuts are visible in the PCF Sigma, a predecessor to the Attune product.

It is my understanding that following a series of to cement -tibial baseplate debonding failures., DePuy completed a optimization project which resulted in the Attune S+ Technology which featured tibial baseplate cement fixation interface design improvements as well as cementation procedure improvements to mitigate the risk of cement-implant debonding.

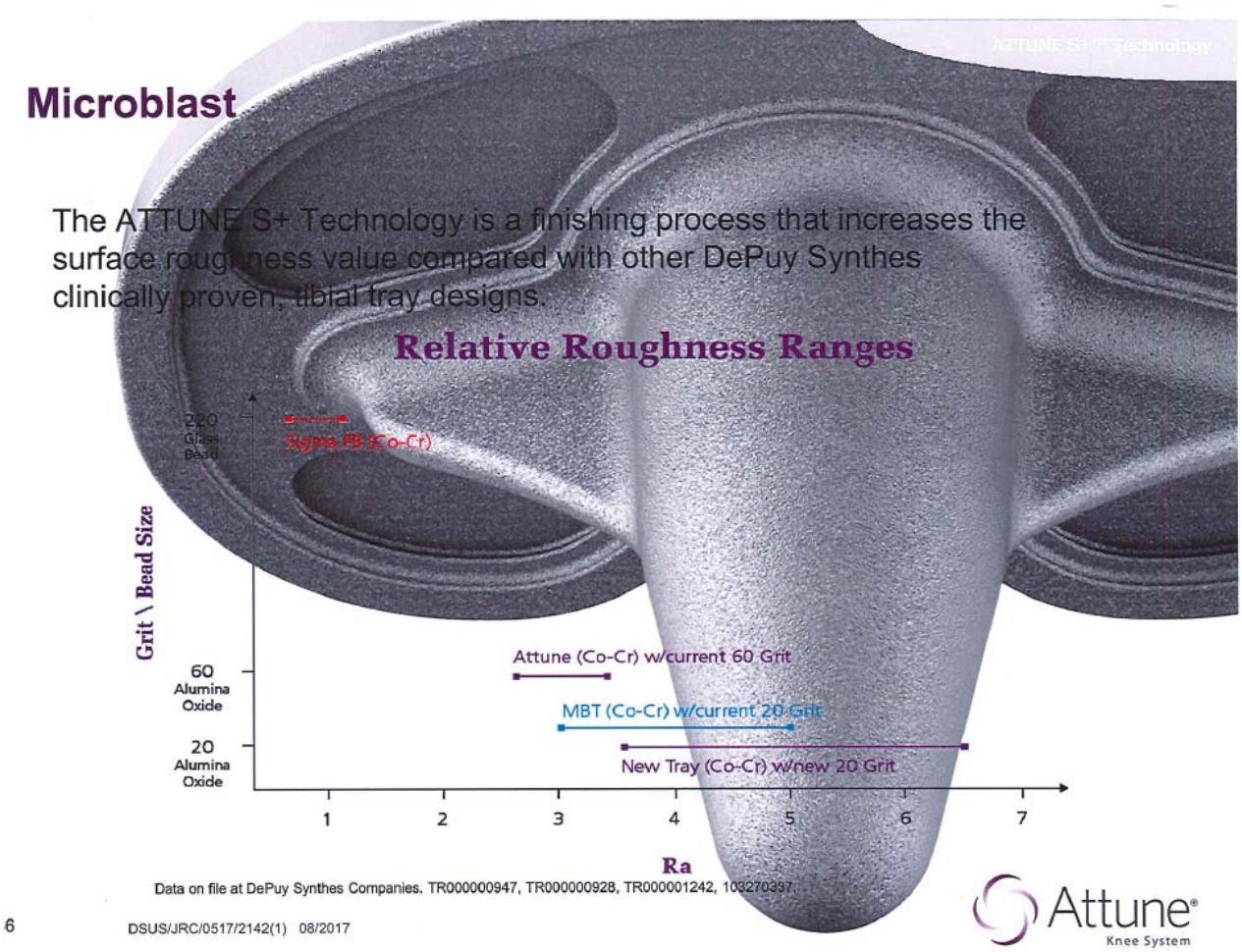


Figure 22: The Attune S+ surface finish has a 20 grit blast finish which slightly rougher than the MTB finish purposefully rejected by DePuy in 2007/2008. [DSUS/JRC/0517/2142(2) 08/2017 Attune S+ Technology]

In response to complaints and reports of unusually high early loosening of the Attune tibial CoCr tray[72], DePuy- Synthes came out with a second Attune tibial tray (S+) which had cement retention features similar to tibial baseplates sold in the 1980s and 1990s: (1) increased surface roughness (use of coarser 24 mesh grit blast); (2) deepened the cement pockets; and applied (3) dovetail undercuts to provided macro-lock features on the Attune S+ tibial tray. DePuy also produced a guide to assist surgeons in optimizing the cement application intraoperatively. This guide emphasized the importance of applying cement to both the well prepared bone and a clean and dry tibial tray. It also emphasized the original/traditional PMMA cementation advice: implant components must not be moved (*or have additional force applied after initial impaction and stabilization)* until the bone cement hardened.

Figure 23a: (**Left**) AGC and Vanguard TKA knee tibial tray undersurface circa 1995. [Source Biomet brochure No. Y-BMT-439_061595©1995]

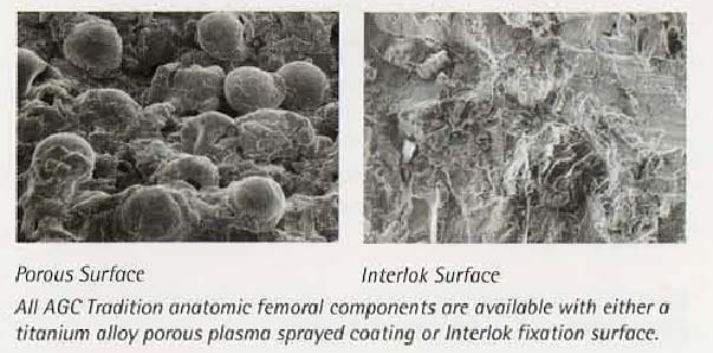


Figure 23b: (**Above**) Close up image of Biomet roughened surfaces for cement fixation. The Porous plasma surface can also be used for cementless fixation. [Source Biomet brochure No. Y-BMT-439_061595©1995.]

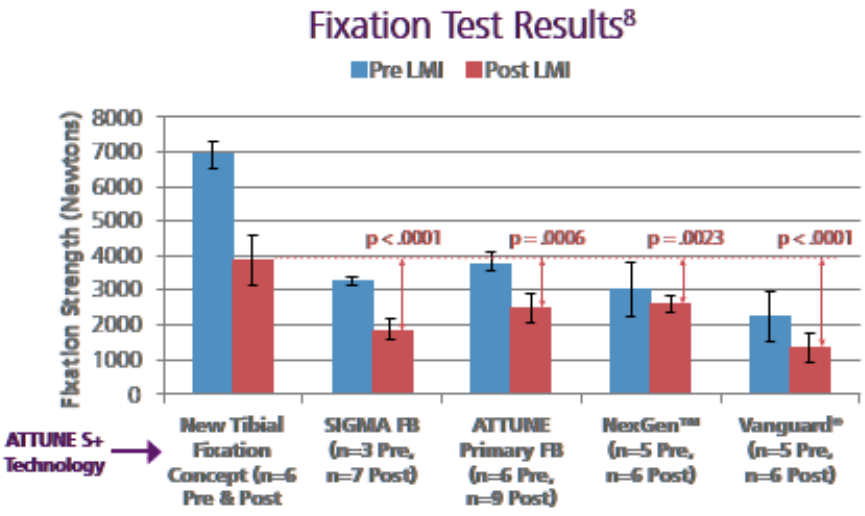


Figure 24: Pull-off (tensile force retention) data from a DePuy Brochure. "**Attune knee system. Advancing Innovation with the Attune S+ Technology**." DSUS/JRC/0617/2207 08/17 ©DePuy Synthes 2017.

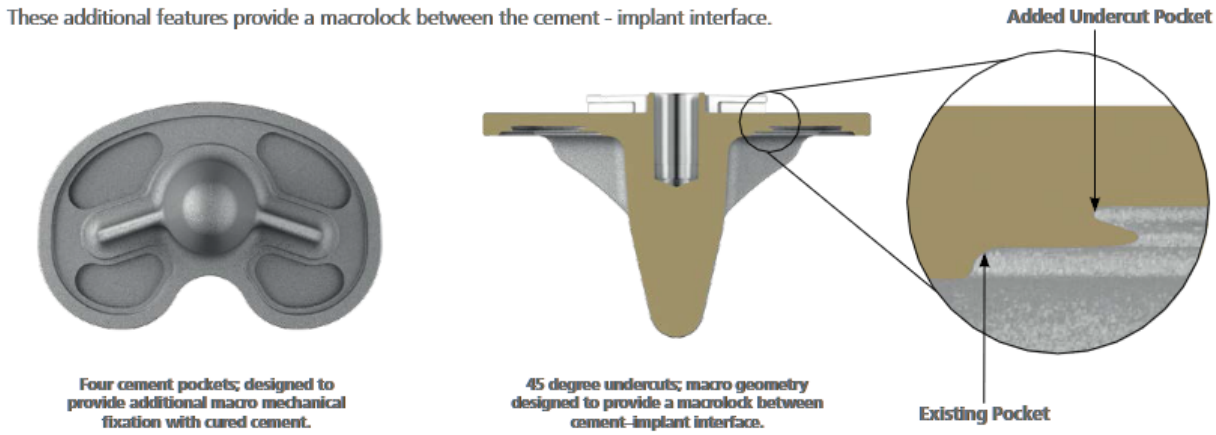


Figure 25: Cement retention features of Attune S+ tibial base-plate from a DePuy Brochure. "**Attune knee system. Advancing Innovation with the Attune S+ Technology**." DSUS/JRC/0617/2207 08/17 ©DePuy Synthes 2017.

Lack of sufficient mechanical interlock[73] is a cause of cement -implant interface debonding in some modern CoCr tibial baseplates, including the first released version of the DePuy Attune[74,75] I have consulted on other Attune tibial baseplate cement debonding cases. I have personally inspected three (3) Conformis customized tibial baseplates , which debonded in a fashion similar to the Attune. This device featured a baseplate with a similar surface texture and little mechanical interlock similar to the original style Attune baseplate.

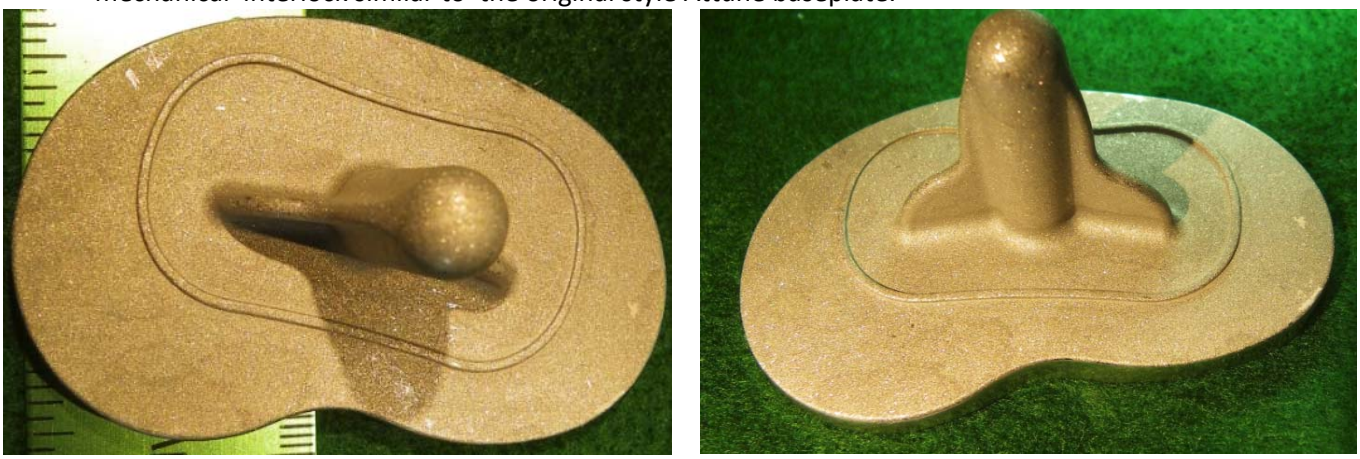


Figure 26: Undersurface of an explanted Conformis CoCr tibial baseplate The radius'd ring was maximally 0.5 mm high. Only a couple very tiny (1 mm) zones of PMMA bone cement macroscopic are visible on the tray. Tiny zones of PMMA flecks may be present. (*The cement interface surface was viewed macroscopically and using a stereoscope*.)

Other modern tibial implants have experienced cement debonding[76] due to:

1. Short stems/keels[77,78];
2. A technique which included moving the joint through a range of motion after cementation but prior to cement hardening (to access knee balance)[79] (Surgeons should avoid manipulation of the joint during cement polymerization to maximize the implant-cement interface strength);

3. Use of high viscosity bone cement which may have inadvertently been applied after the "sticky phase" or the early doughy adhesion stage, potentially due to differences and inconsistencies in the in the bone cement curing rates and lack of bone penetration.[80]

The original Attune design obviously lacked mechanical interlock features on the tibial baseplate. This has been shown by testing by DePuy as shown in its brochures and by others.[81, 82, 83, 84, 85]

Kelly et al[86] stated that failure at the cement-implant interface may be due to poor bonding between cement and implant which can be reduced by changing the undersurface features of the tibial tray. They documented that the additional cement pockets showed a significantly reduced relative motion between implant and bone and a significantly increased maximum failure load. Similar to my assessment, these authors stated that the reasons for early failures of Attune TKAs include certain features of the initial Attune baseplate design including the the tapered keel, a smooth undersurface without cement containment rails, which, in combination, may have predisposed this first generation baseplate to early failure.

Concerning their in vitro testing of Attune and Attune S+, Kelly et al [87] stated:

> " 2nd generation tibial baseplate had significantly greater pullout strength when compared to the 1st generation and control baseplates both with and without the presence of marrow fat. We believe that the improvement in fixation was due to certain design features of the 2nd generation tibial baseplate. The macrolock feature of the 2nd generation baseplate includes four cement pockets with 45-degree undercuts, which are designed to provide additional fixation of the cured cement at the cement-implant interface. In addition, the microblast surface feature of the baseplate increases the surface roughness of the tibial tray, which is designed to limit lipid infiltration, thus improving cement-implant interdigitation. In addition, the roughened surface has a greater surface area for cement adhesion than a smoother surface [18]. In a similar cadaveric study by Maag et al, the 2nd generation tibial baseplate had a greater fixation strength pre and post lipid/marrow infiltration (LMI) when compared to several other tibial baseplates [13]."

Julie Sprafka who weight between about 214 and 220 lb, was not an unusually heavy person and she was not overly active. Her tibial bone interface did not resorb or break down. The primary cause for tibial implant debonding in her right knee was the lack of mechanical interlock features on the tibial baseplates.

In Summary:

The cement interface surface of the tibial implant baseplate in the Attune tibial base plate implanted into Julie Sprafka is defective in design. There are no macro lock features, and given this the surface is too smooth. The shallow cement pocket with radius'd edges offer little resistance to shear forces at the cement-implant interface. Given that the Attune tibial baseplate had no substantial mechanical capture feature to secure the bone cement, the specification of a 60-grit blast surface finish on the baseplate CoCr cement fixation surface with an Ra equivalent of up to about 2.5 to 3.5µm is a design defect.

Assurance of Safety and Function

The manufacture and its **design team have the responsibility to test their products for the ability to withstand the end use environment.** The product must be safe for used under reasonably foreseeable use conditions.

DePuy's failure to use rougher cement fixation surfaces textures or 3D porous coatings and other macro lock geometrical features deprived Julie Sprafka of the level of protection that other manufacturer's products provide.

Manufacturer's Reporting Responsibilities

Revision of a total knee due to cement interface debonding is a device related failure and is a reportable event. Tibial baseplate loosening by debonding at the implant interface that requires intervention (revision) to address pain prevent permanent impairment (serious injury) must be reported to the FDA within 30 days of notice to the manufacturer.

Manufacturers are required by law to have systems in place to provide timely identification, communication, investigation and reporting of events to the FDA. Sales force including affiliates and distributers that for most of the instances is the first point of contact for product complaints. Timely internal reporting and investigation of events and subsequent timely reporting to regulatory authorities is mandated. Effective systems include consistent training of employees and sales associates including affiliates and distributers to recognize reportable events and follow complaint-reporting processes.

Per CFR - Code of Federal Regulations Title 21 21CFR803 and the FDA:

Sec. 803.17[J]
If you are a user facility, importer, or manufacturer, you must develop, maintain, and implement written MDR procedures for the following:
(a) Internal systems that provide for:
(1) Timely and effective identification, communication, and evaluation of events that may be subject to MDR requirements;
(2) A standardized review process or procedure for determining when an event meets the criteria for reporting under this part; and
(3) Timely transmission of complete medical device reports to manufacturers or to the FDA, or to both if required.
(b) Documentation and recordkeeping requirements for:
(1) Information that was evaluated to determine if an event was reportable;
(2) All medical device reports and information submitted to manufacturers and/or FDA;
(3) Any information that was evaluated for the purpose of preparing the submission of annual reports; and
(4) Systems that ensure access to information that facilitates timely follow-up and inspection by the FDA.

Sec. 803.50[K]

[J] https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfCFR/CFRSearch.cfm?fr=803.17
[K] https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfCFR/CFRSearch.cfm?fr=803.50

If you are a manufacturer, you must report to the FDA the information required by § 803.52 in accordance with the requirements of § 803.12(a), no later than 30 calendar days after the day that you receive or otherwise become aware of information, from any source, that reasonably suggests that a device that you market:

(1) May have caused or contributed to a death or serious injury or

(2) Has malfunctioned and this device or a similar device that you market would be likely to cause or contribute to a death or serious injury, if the malfunction were to recur.

Sec. 803.52[L]

An outcome is considered a serious injury if it is:

(i) A life-threatening injury or illness;

(ii) A disability resulting in permanent impairment of a body function or permanent damage to a body structure; or

(iii) An injury or illness that requires intervention to prevent permanent impairment of a body structure or function;

Medical facilities are required to notify the manufacture, of serious injury events within 10 working days (or notify the FDA if the manufacture is unknown). [Sec. 803.30, Subpart C, User Facility Reporting Requirements]. Deaths, however, must be reported directly to the FDA. The Orthopaedic surgeons are not, individually, required to notify the FDA or the manufacture, but may notify either.

Discussion of Implant Failures

Attune Tibial component design has been implicated in early aseptic loosening of cemented TKA (Bonutti et al[88], 2017; Hazelwood et al[89], 2015).[90] Murphy et al[91] (2021) also noted that the Attune tibial component's smooth under surface design has led to an unusually high early failure rate. Within two years, their patients complained of anterior knee pain and instability of the knee with ambulation. Radiographic evaluation showed varying degrees of loosening. Intraoperative evaluations found gross loosening of the tibial component, lacking any adherence to the cement.

The clinical results from case reports are conflicting. For example, similar to Ranawat et al[92] and developing surgeons, Willburg and Oberberg[93] (2022) noted that in the small study of 30 PFC and 30 Attune, there was no evidence of increased radio lucent lines (RLLs) or loosening in the Attune group. But Giaretta et al[94] reviewed 228 primary cemented TKAs using Attune Total Knee Replacement System which were implanted between 2014 and 2018 concerning short-term clinical and radiographical outcomes and survival. Varus and radiolucent lines were detected in 43 knees (22,4%), even though the short term survival rate was 98.4% at 2 years and 97.4% at 5 years. At short-term follow-up the Attune Knee Replacement System had excellent clinical and radiographical outcomes and good results regarding revision rate, but due to high incidence of radiolucent lines, the authors noted that the patients should be closely monitored even though they showed no clinical evidence for loosening.

Surgical and cementing technique have been implicated, including the potential adverse effect of fatty

[L] https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfCFR/CFRSearch.cfm?fr=803.

infiltration causing weakening of the implant-cement bond.[95]

Cerquiglini et al[96] (2019) studied the cement attachment to retrieved Attune vs PCF predecessor devices finding the lowest area of cement attachment post retrieval on the Attune.

Cerquiglini et al[97] further noted that other studies[98,99] (in 2015 and 2016) suggested high-viscosity cement associated with early loosening of the tibial tray; however, in both of the cote case series, the tibial tray designs investigated (Biomet Vanguard (Zimmer Biomet), PFC Sigma RP (DePuy) and Smith & Nephew Genesis (Smith & Nephew, Memphis, Tennessee) showed an absence of cement pockets, as with the Attune design, and therefore may be an example of a design problem rather than a cement problem.

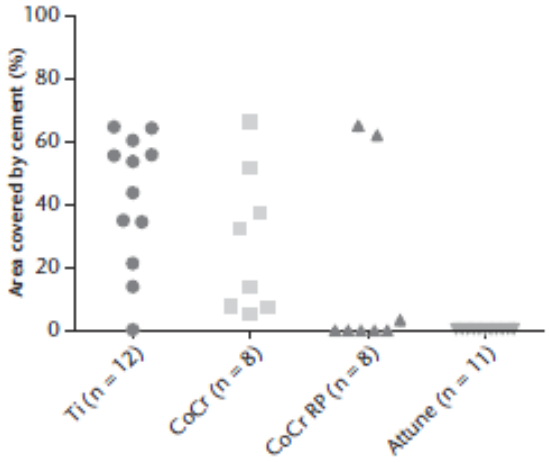
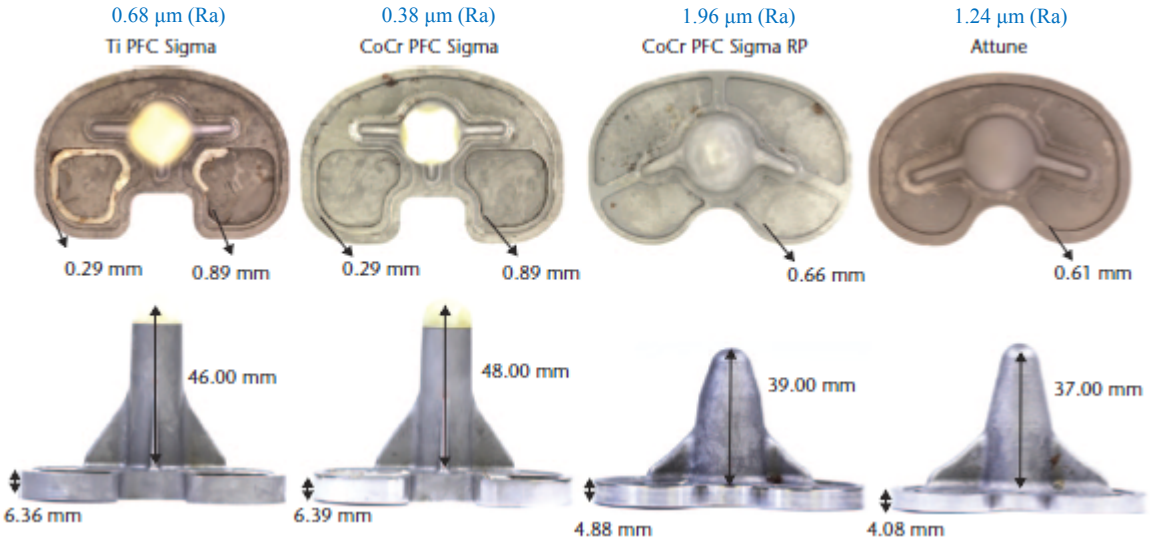


Figure 27: Retrieval Analysis of the Attune vs PFC tibial tray backsides**.** Graph showing the percentage of area covered by cement in the four designs analyzed. The difference between the Attune and the old PFC Sigma designs (titanium (Ti) and cobalt-chromium (CoCr)) was significant ($p < 0.05$). RP, rotating platform.[100] Design features analyzed by visual inspection: undercuts or cement pockets, peripheral lips, tibial tray thickness, and stem length.

Buller et al[101] analyzed results for 10,014 patients in a knee registry (Jan 2007-Dec 2016). The results showed that high viscosity cement (HVC) to be independently associated with higher odds of revision for aseptic loosening (odds ratio 2.26). Implant manufacturer, implant design, and cement brand all impacted the odds of undergoing revision for aseptic loosening.[102,103, 104] For example , application of the cement to the metallic surface of the tibial base tray in the sticky phase, prior to the doughy phase, increases adherence. However, the intrinsic properties of the HV Cement such as viscosity variations can make setting behavior (timing) somewhat unpredictable for certain brands. Torino et al[105] (2022) reported a 2 year revision rate of 2.4% (18 of 742 knees with at least 2 year follow up or earlier revision) for the original Attune. Aseptic loosening was the leading cause of revision for a 2-year aseptic loosening revision rate of 1.3%. All cases of aseptic loosening demonstrated debonding at the tibial implant-cement interface. The mean time to revision was 22.6 months (range: 9.8-36.3 months). Surgeries were performed by 8 surgeons using 5 different types of cement. Taken individually, the 2 factors that were significantly associated with all-cause revision were cement manufacturer (17.1% DJO Surgical high-viscosity cement vs 0.0%-2.2% for all others), and surgeon volume (10.5% low volume surgeons vs 1.6% high-volume surgeons). The authors concluded that surgeon case volume and cement viscosity were factors associated with an increased rate of early failure due to tibial baseplate implant-cement interface debonding.

Refsum et al[106] (2019) completed scoping literature review and based on that provided nine guidelines for the cementing technique in TKA. Among other things, the guidelines indicated

that cement should be applied to both implant and bone and that full cementation should be applied on both the stem/keel and undersurface of the tibial component if using metal backed components and that there is evidence from in vitro studies that applying the cement to the implant early, 2 minutes after mixing, increases the implant cement bonding. Hegde et al[107] studied tourniquet in TKA and found that use improves cement penetration and reduces radiolucent line progression. The also noted that dryer surfaces during cementation may improve penetration. Sun et al[108] found the same in a literature Meta analysis, the application of a tourniquet increases the thickness of the tibial bone cement penetration, mainly in zone 3 on the anteroposterior (AP) view.



Tibial tray design	Tibial tray backside roughness, µm	Stem roughness, µm
Ti PFC Sigma	0.68 (0.57 to 0.74)	0.85 (0.79 to 0.93)
CoCr PFC Sigma	0.38 (0.30 to 0.42)	0.60 (0.52 to 0.62)
PFC Sigma RP	1.96 (1.84 to 2.23)	2.26 (2.11 to 2.71)
Attune	1.24 (1.21 to 1.40)	1.29 (1.15 to 1.59)

Ti, titanium; CoCr, cobalt-chromium; RP, rotating platform

Figure 28: Retrieved product roughness measurement.[109] Talyrond 365 measurements revealed that CoCr PFC Sigma presented the lowest value of tibial tray surface roughness, with a median value of 0.38 µm (Ra), followed by Ti PFC Sigma, Attune and PFC Sigma RP, with median values of 0.68 µm, 1.24 µm, and 1.96 µm, respectively. The same trend was also observed in the stem roughness but with higher values. The table shows these results, displaying median values and interquartile range (IQR) values.

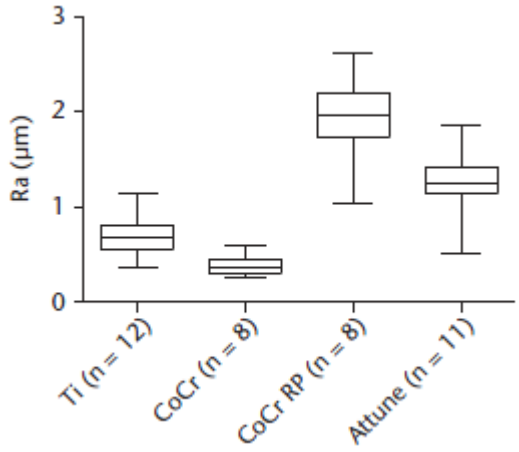


Figure 29: Tibial tray roughness (Ra) [Cerquiglini et al[110]]

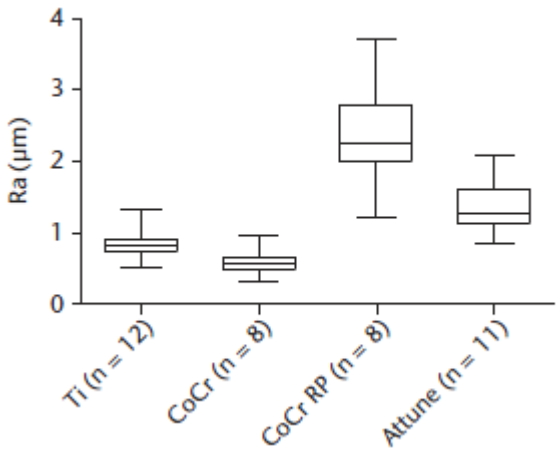


Figure 30: Stem surface roughness (Ra) [Cerquiglini et al[111]]

Using a simplified in vitro test, Kelly et al[112] (2021) documented that the presence of bone marrow during cementation of a tibial base plate significantly decreases axial pullout strength of a tibial baseplate laboratory models as DePuy surgeons and staff had presented at meetings in 2017 and 2018[113]. All Attune 1st generation baseplates exhibited debonding at the cement-implant interface. The Attune S+ 2nd generation tibial baseplates required significantly more force to failure.

A study by Billi et al [114] (2019) confirmed that applying cement to both the implant and the bone was protective of implant cement failures caused by lipid contamination.

Kaptein et al[115] (2020) reported 2-year results from a randomized controlled trial comparing the Attune vs PFC-sigma cemented cruciate-retaining knee prosthesis in 74 patients. In the first two postoperative years, the initial version of the Attune tibial component showed relatively more backwards tilting and radiolucent lines at the implant-cement interface than its predecessor the PFC-sigma, although it was not not inferior with respect to overall migration. In theory, a cemented tibial component should have no migration, but the transverse- (Rx) and longitudinal-axis (Ry) rotations of the Attune were statistically significant and larger than for the PFC-sigma indicating more backward tilting and more external rotation of the Attune tibial component. **Radiolucencies at the implant-cement interface were mainly seen below the medial baseplate: 17% in the Attune and 3% in the PFC-sigma at two weeks, and at two years 42% and 9% respectively (p = 0.001). The version of the Attune tibial component examined in this study has subsequently undergone modification by the manufacture.**

Kaptein et al[116] stated:

> "Based on the results of this paper showing increased backwards tilting, the relatively large number of radiolucencies, confirmed by the literature, worrying reports about increased revision rates as a result of cement debonding, the larger revision rates in one of the registries and the fact that the manufacturer changed the design of the implant only four years after its first introduction, we would like to raise concerns about the further widespread use of this specific Attune tibial implant design."

Rebgetz et al[117] noted that retrieval analysis performed at their institution identified two knee tibial components with a higher-than-expected revision number due to aseptic or mechanical loosening for the number retrieved. These same implants had been reported to have high incidence of aseptic loosening in limited case series without showing unacceptable revision rates in national registries. The prosthesis identified were ATTUNE (DePuy Synthes)(41% of retrievals, *n* = 64) and the Genesis II (Smith & Nephew) (34% of retrievals, *n* = 151).

To investigate the reasons, Rebgetz et al[118] (2021) completed in vitro testing of tibial baseplate fixation strength noting that contamination of the cement prosthesis interface demonstrated a lower pullout. Designs with both keel and baseplate cemented showed higher pullout strength compared to cementing the baseplate alone. In addition, the use of low-viscosity cement resulted in a significantly higher failure force compared to high-viscosity cement when cementing the baseplate alone. With regard to the Attune S+ component, authors cited Kelly et al[119] who documented that the additional cement pockets showed a significantly reduced relative motion between implant and bone and a significantly increased maximum failure load. The authors attributed this enhanced implant stability of the tibial component to the additional cement pockets, which allow for improved mechanical cement adhesion.

Jaeger et al[120] (2020) also completed in vitro testing of tibial baseplate fixation strength noting that contamination of the cement prosthesis interface demonstrated a lower pullout. Furthermore, the Attune did not retain cement on pullout under any conditions, while the Attune S+ retained cement at least in the cement pocket undercuts and in cases with less lipid intrusion, over a large percentage of the surface. (See Figure 31).The authors noted that preoperative bone mineral density (BMD) showed no statistically significant difference in relative motion in the implants cemented into cadaver tibia. The also concluded that from a biomechanical point of view, the additional cement pockets of the component have improved the fixation performance of the implant.

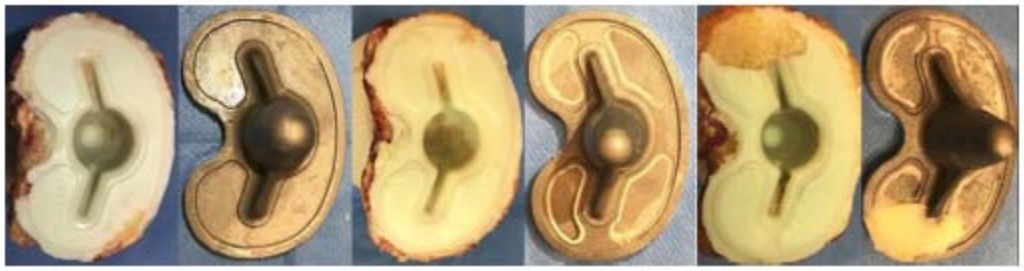


Figure 31: Left two images: Attune. Centre: Attune S+ without significant areas of adherent cement. Right: Attune S+ with adherent cement (**Jaeger** et al[121]).

Knee motion during cement polymerization is associated with significant decreases in tibial implant fixational strength. Reduction in implant pullout strength was identified with each implant design with motion and varied between designs. Limiting motion while cementing the tibial implant is required to maximize fixation strength.

Staats et al[122] (2019) also reported Attune tibial component cement debonding, with up to 35.1% radiolucencies in 276 cemented Attune knee prostheses, compared to 7.5% in 253 PFC-sigma knee prostheses at 12 months postoperatively. Both components are cemented in a single

step. According to the authors, Attune's only option at the time was to use a keel punch, which prepared the tibia for a cement mantle with at least 1 mm around the keel. A combination of high-viscosity cement, the additional preparation for the cement mantle and movement during the interlocking-process (e.g. extension or even hyperextension) may lead to an increased force on the anterior aspect of the tibial baseplate causing the keel shifting dorsally. This mechanism may lead to radiolucent lines, especially around the keel. The PFC tray we prepared with for a press-fit cementless keel. Otherwise, there were no differences in the cementing technique between the Attune and the PFC-group. Since high-viscosity cement was used in both groups, the cement itself did not influence the decreased attachment on the tibial component. The authors noted that possible influential factors were reduced to shortcomings in surgical technique or implant-related issues. A line-to-line keel-punch for press-fit tibial preparation is now available for the Attune. Too much movement during the cement interlocking- phase. This may especially be a problem when both components are cemented in a single step. This is the reason the authors report that they now tend to perform the cementation of the tibial and femoral component in two separated steps. The authors concluded that the radiographic results of their study together with other findings in the literature should raise concern that the design of the tibial component may have its disadvantages even though no evidence for a higher complication- or revision rate could be detected in their short term study which did not include any form of functional assessment and, therefore, cannot provide any information about the level of patient satisfaction.

In 2020 Sadauskas et al[123] investigated a case series investigates commonalities between 9 patients who underwent revision TKA and were found to have complete debonding at the cement-implant interface of a femoral and/or tibial components. Attune was among the revised devices. Only 3 preoperative radiographs were indicative of aseptic loosening, and all patients had an infectious etiology ruled out. The average time to revision was 2.6 years with a range of 1.3 to 4.75 years.

Figure 32a: Intraoperatively removed debonded tibial component (Sadauskas et al[124])

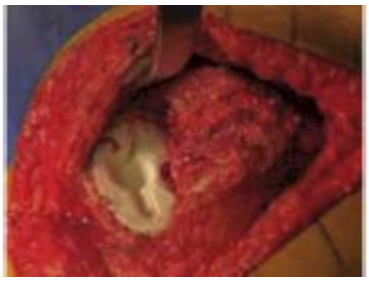


Figure 32b: Fully debonded tibial component in vivo. (Sadauskas et al[125])

Rodríguez-Collell et al[126] studied tibial implant cementation technique and found that the best layer is created by double cementation (bone and metallic surfaces) with bone restrictor. This technique uses twice the amount of cement (40 g vs 20 g) than the other techniques; it ensures deeper cement penetration into the bone structure, with acceptable widths at both the epiphyseal and metaphyseal levels. Full cementation technique on the metallic tibial tray and stem can obtain good bone cement interdigitation at the epiphyseal surface, but rather poor interdigitation at the metaphyseal level. The authors noted that Grupp et al[127] and Peters et al[128] previously reported the same. While Peters et al[129] noted that the stability of surface-cemented tibial components may be related to the depth of cement penetration, in their in vitro test under an eccentric load simulating three times body weight for 6000 cycles, there seemed to be no difference in the micromotion of either tibial component implanted with surface or full cementation. Additionally, no difference in the average depth of cement penetration was

detected between fixation techniques or stem types. However, the authors noted that the loading protocol only modeled the vertical loading during walking gait, not stability under torsion or shear.

Martin et al[130] (2022) like many others before them, evaluated pull out strength, but noted that pullout strength does not necessarily represent implant loosening. Although they believe that lower pullout strength may correlate with loosening, they are not able to conclude an absolute pullout strength threshold that would result in an implant at risk of failure. The contemporary TKA implants studied included A: DePuy Attune S+ (Warsaw, IN); implant B: Zimmer Persona (Warsaw, IN); implant C: Stryker Triathlon (Mahwah, NJ); implant D: Biomet Vanguard (cruciate finned tray) (Warsaw, IN); and implant E: Smith and Nephew Genesis II (Memphis, TN). However, the Smith and Nephew Genesis II tray was not be evaluated for pull out due to fixture problems. After impaction of the tibial implant, the no motion cohort was held still with axial compression of the tibial tray until the cement cured. Alternatively, the motion cohort was held with axial compression for 7 minutes (from cement mixing) followed by a range of motion and stability assessment. The knee was maximally flexed and then extended, followed by application of a valgus and varus stress to assess ligamentous stability. Motion during total knee cementing significantly decreases tibial implant fixation strength and devices with implant-cement failures had significantly lower pullout strength.

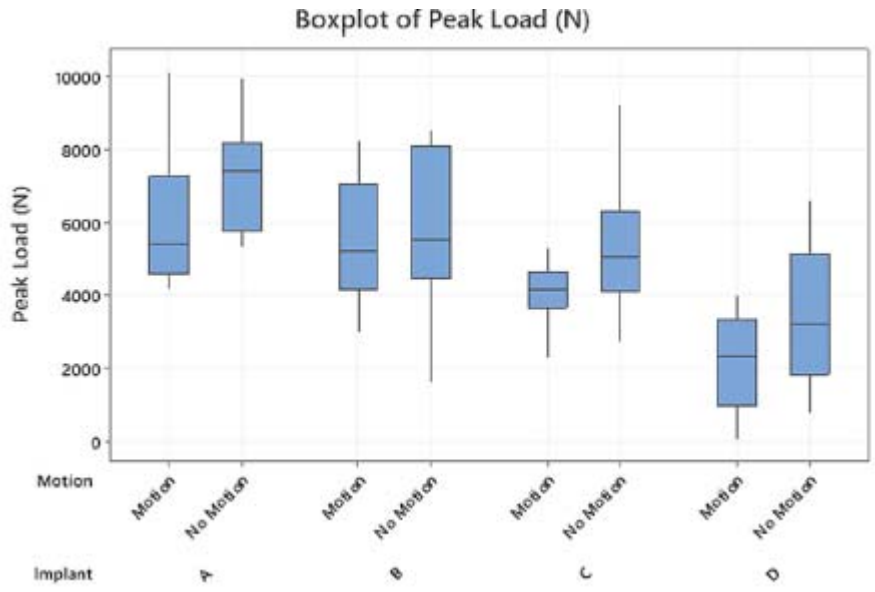
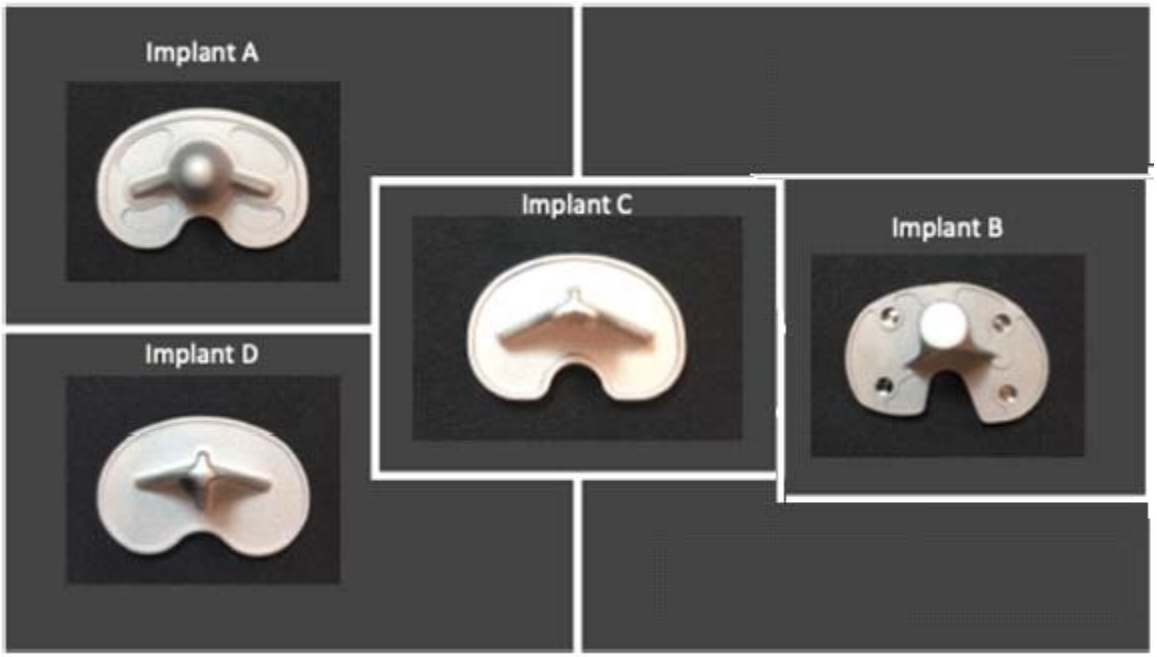


Figure 33: Boxplot of peak load (N) by implant and motion. (Martin et al[131]2022)



Implant Pull-Out Strength for Each Failure Pattern.

Implant	Implant-Cement Failures (#)	Average Pull-Out Strength (N)	Bone Failures (#)	Average Pull-Out Strength (N)	Mixed Failures (#)	Average Pull-Out Strength (N)
A	5	6,783	10	6,314	1	9,957
B	8	4,692	6	6,391	2	7,268
C	1	2,753	6	4,938	9	4,739
D	16	2,841	0	N/A	0	N/A

N/A, not available.

Figure 34: The 4 implants evaluated for pullout in the Martin et al[132] study & results.

Over time, the steps for cementation have been re-evaluated including the timing of cement application, the use of pulsatile lavage, the use of a tourniquet, and the type and viscosity of cement. Martin et al[133] demonstrated the importance of limiting motion during the cementing process to limit lipid contamination of the implant-cement interface. [134]

MAUDE Reports: A search of the FDA Manufacturer and User Device Experience (MAUDE) website identified 2327 medical device reports (MDRs) for the Attune Fixed Bearing Tibial Base product family from January 1, 2010 through June 30, 2020. There were 1900 mentions of loosening (82%). Many complaints specified loosening at the implant-cement interface. At this time, my client has not been provided complaint files, complaint summaries, CAPA reports or post market surveillance reports for the Attune tibial baseplates for my review. I may have additional comments upon review should those documents be provided in this matter.

It has been my experience that orthopedic device manufacturers fail to capture a significant number of device revisions in their complaint systems for several reasons. In some cases, revisions are done by a different surgeon/location where another manufacturer's device is implanted and the manufacturer's representatives are not notified. Sometimes manufacturer's distributors or sales representatives simply fail to report the revision. The debonding issue in this matter may also be under reported clinically because it can be difficult to diagnose from radiographs according to Dr Bonutti. In his series of 15 debonded Attune tibial baseplates, the loosening was only visible on x-ray 13% of the time (2 of 15).

Bonutti et al[135] concluded:

> "We believe that this complication is underreported due to failure of radiographs to assess loosening. In addition, MAUDE database reporting is not consistent and competing companies cannot provide data on the revised components. In patients who have negative workup for a painful joint, one must consider the diagnosis of debonding."

Under reporting in combination with a lack of in-depth investigation of the causes for the revision procedures renders the manufacturer's complaint system statistics unreliable. I have reason to be concerned about the efficacy of DePuy processes based on FDA audit observations.[M] For example, three FDA auditors in 2011 issued Form 483 observations to DePuy concerning deficiencies identified in DePuy' s complaint handling and Corrective and Preventative Action(CAPA) processes, statistical analysis errors, as well as instances of DePuy's failure to report serious injuries to the FDA as required by 21CFR803 (Sec. 803.50, 803 .12(a) and 803.52). Taken in totality, the observed deficiencies noted by the FDA auditors into question the reliability of DePuy complaint statistics. (Refer to Appendix E).

Statistics for rates of specific types of failures for products often come from a complaint system known to be missing a large number of procedure failures. Sometimes the manufacture's rate is based on the manufacturer's sales records that can be much higher than the actual implantations due to stocking by distributors or hospitals. It might be helpful to have clarification on how DePuy calculated the revision rate for Attune tibial baseplates at issuein thiss case verses Attune S+ tibial baseplates and the PFC predecessors during its post market surveillance reviews.

Deponding of the cement from the Attune tibial tray may not have been separated out in the complaints or captured in the complaint analysis summaries. Some failures coded as loosening, instabilty, infection or simply pain, may actually have been failures due to debonding. Furthermore, the rate of tibia debonding may not be the same as the rate of revision. Less demanding patients (older, lighter, less active) may take longer to develop debilitating symptoms. Some patients may have a debonded baseplate, but the symptoms (pain, instability or function loss) are at least initially, not sufficient enough for them to submit to a revison surgery. Many revisions are performed for more than one reason such as loosening, osteolysis, pain, instability, function loss, or infection. The manner in which the failure is coded will alter the statistical trend analysis. Cement debonding cases with other assocaited failure modes may not have been categorized as cement debonding failure[N].

The Attune cement tibial tray cement debonding failure statistics provided by DePuy are questionable because of under reporting for the reasons discussed herein (underreporting by the DePuy sales force, by surgeons, by patients suffering in silence, or due to insufficient investigation). The DePuy failure statistics are therefore of questionable reliability relative to the specific issues at hand in this matter.

[M] Copy of 483 form to Mary E Riggs, dated 06/07/2011; also www.fdanews.com/articles/139729-depuy-orthoPEDICS-483-notes-capa-procedures-complaints-system

[N] Cement debonding failure was frequently worded as "PATIENT WAS REVISED TO ADDRESS TIBIAL LOOSENING AT THE CEMENT/IMPLANT INTERFACE" in FDA MAUDE reports.

Others have documented problems with orthopedic manufacturers' post market surveillance. Using registry data, Sadoghi et al.[136]reported that the manufacturers' post-marketing surveillance appears to be unable to ensure a comprehensive overview of the actual device malfunction rates. For example, in the case of unambiguous situations such as ceramic head fractures, one of the world's leading manufacturers publishes incidences, but the actual rate is supposed to be three times higher in clinical practice. According to worldwide register data, the fracture rate for ceramic heads was five times higher than reported to the manufacturer.

Labek et al[137] reported that the published results of the clinical studies involving many of the arthroplasty implants, especially implants developed in the United States, were highly influenced by reports from the center that developed the implant. This often had a substantial effect on the reproducibility of the outcome data. For the majority of implants for which the revision rate calculated from the published clinical studies was very low compared with the rate calculated from the registry data, the developing institution accounted for 39% to 100% of the published outcome data for the implant. In contrast, the published results were usually reproducible in clinical practice if <25% of the published data were reported by the developers.

In order to assess the communication of warnings and the reliability of the post market surveillance data and trend data accumulated by DePuy for Attune tibial baseplates at issue it would be helpful to document information known by case-specific sales persons . The salesperson is the point person between the surgeon and the company, the product information, including any warning communications. It would be helpful to document what was known by the salesforce and what was actually communicated to surgeons. It would be helpful to understand what the salespersons understood to be the risks, benefits, and relative performance of the Attune tibial baseplate products compared to alternative PFC products and the new Attune S+ product over time. It would also be helpful to document what that sales person shared with implanting and revising surgeons.

It would be helpful to understand, for each implanting and explanting surgeon the information, such as brochures, training, letters, e-mail, discussion or other communications that sales person, or DePuy Corporate, provided to the surgeon concerning the Attune tibial baseplate product risks, product benefits, frequency of revision in the USA, in his/her sales territory and globally, as well as his or her understanding of the causes for revision.

At this time documents and/or testimony related to the effectiveness of the DePuy Synthes complaint handling processes have not been provided for this case. At this time testimony from sales, regulatory or quality staff concerning complaint processing, have not been provided to Plaintiffs' counsel in order for me to review. Nor has testimony or statements from the implanting surgeon been provided for my review. It is my understanding that 30b(6)depositions of DePuy staff are still pending.

I may formulate additional opinions concerning DePuy's conduct regarding the communication of the dangers of the Attune cemented tibial tray over time, and DePuy's compliance with Title 21 21CFR803 Sec. 803.17 and 803.50, and DePuy's conduct should additional relevant information be provided to Plaintiffs' counsel in order for me to review, or via deposition.

Registry Data for Attune PS

The 16th annual report 2019 National Joint Registry (NJR) (www.njrcentre.org.uk) reported the Kaplan Meyers estimates of cumulative revision for Attune cemented PS of 4.08% at 5 years[O]. In the Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR) for data period September 1, 1999 to December 31 ,2018, the 5-year cumulative percent revision for Attune PS , all fixation methods, was 2.3%. Attune patient use in these two Registries began in 2014.

Infection dominates the early revision for TKA, but after ~ 13 years, aseptic loosening is reported as the leading cause of TKA revision in the Australian National Joint Replacement Registry(AOANJRR). [AOANJRR 2022 (page 210)]

Using data from 1999-2017, Lewis et al[138] reported that the AOANJRR data showed no difference in survivorship for the PFC Sigma CR (n = 33,770) and Attune CR (n = 8729). The cumulative percent revision (CPR) was 2.7 for Attune and 2.6 for PFC-Sigma. (At that time the Attune mean follow up was only 2 years and PFC-Sigma 7 years).

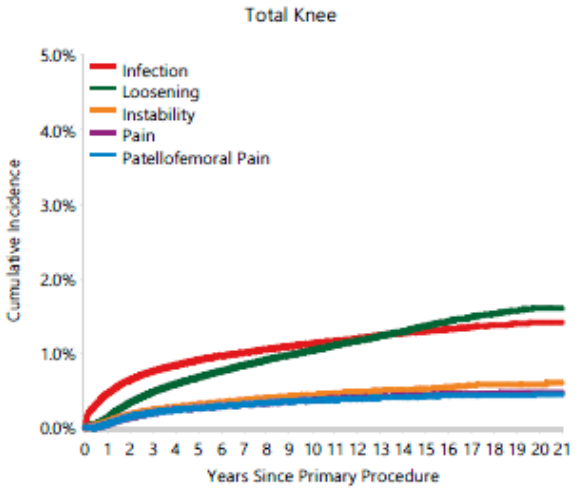
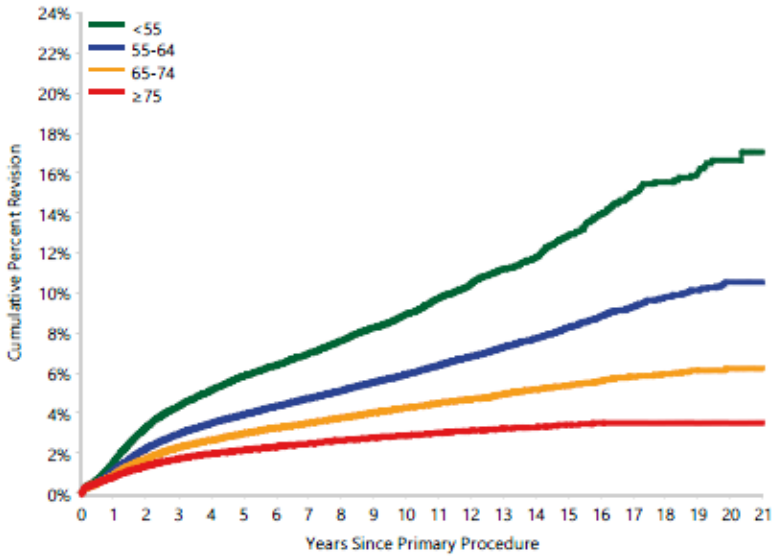


Figure 35: AOANJRR 2022, Figure KT8, Cumulative Incidence Revision Diagnosis of Primary Total Knee Replacement (Primary Diagnosis OA)

Figure KT9 Cumulative Percent Revision of Primary Total Knee Replacement by Age (Primary Diagnosis OA)



HR - adjusted for gender

<55 vs ≥75
0 - 6Mth: HR=1.32 (1.17, 1.50), p<0.001
6Mth - 1.5Yr: HR=2.96 (2.70, 3.25), p<0.001
1.5Yr - 2Yr: HR=3.44 (2.96, 4.01), p<0.001
2Yr - 3.5Yr: HR=3.16 (2.85, 3.50), p<0.001
3.5Yr - 4Yr: HR=3.87 (3.18, 4.70), p<0.001
4Yr - 4.5Yr: HR=3.86 (3.13, 4.75), p<0.001
4.5Yr - 7.5Yr: HR=3.68 (3.29, 4.12), p<0.001
7.5Yr - 8.5Yr: HR=4.92 (4.05, 5.97), p<0.001
8.5Yr - 9.5Yr: HR=4.40 (3.49, 5.54), p<0.001
9.5Yr+: HR=6.16 (5.47, 6.95), p<0.001

55-64 vs ≥75
0 - 6Mth: HR=0.99 (0.91, 1.09), p=0.895
6Mth - 9Mth: HR=1.83 (1.63, 2.07), p<0.001
9Mth - 1.5Yr: HR=1.98 (1.83, 2.15), p<0.001
1.5Yr - 2Yr: HR=2.24 (1.98, 2.54), p<0.001
2Yr - 2.5Yr: HR=2.04 (1.84, 2.27), p<0.001
2.5Yr - 3.5Yr: HR=2.14 (1.95, 2.35), p<0.001
3.5Yr - 4.5Yr: HR=2.45 (2.20, 2.74), p<0.001
4.5Yr - 8Yr: HR=2.46 (2.26, 2.66), p<0.001
8Yr+: HR=3.28 (3.00, 3.59), p<0.001

65-74 vs ≥75
0 - 6Mth: HR=0.95 (0.87, 1.03), p=0.194
6Mth - 1.5Yr: HR=1.44 (1.34, 1.55), p<0.001
1.5Yr - 2Yr: HR=1.58 (1.40, 1.79), p<0.001
2Yr+: HR=1.62 (1.54, 1.72), p<0.001

[O] Kaplan Meyers estimates of cumulative revision for Attune - all styles of 2.67% at 5 years.

Table KT9 Cumulative Percent Revision of Cemented Primary Total Knee Replacement by Prosthesis Combination

Femoral Component	Tibial Component	N Revised	N Total	1 Yr	3 Yrs	5 Yrs	10 Yrs	15 Yrs	20 Yrs
Attune CR	Attune	473	20427	0.9 (0.8, 1.0)	2.3 (2.1, 2.5)	3.1 (2.8, 3.4)			
Attune PS	Attune	206	10431	0.9 (0.7, 1.1)	2.1 (1.8, 2.4)	2.6 (2.3, 3.0)			
PFC Sigma CR	MBT	42	1190	0.8 (0.5, 1.6)	1.9 (1.2, 2.8)	2.3 (1.6, 3.3)	3.4 (2.5, 4.6)	3.8 (2.8, 5.3)	
	PFC Sigma	492	13507	0.8 (0.7, 1.0)	2.1 (1.8, 2.3)	2.6 (2.4, 2.9)	3.6 (3.3, 4.0)	5.2 (4.7, 5.8)	7.0 (5.8, 8.5)
PFC Sigma PS	MBT	346	6153	1.0 (0.8, 1.3)	2.9 (2.5, 3.4)	3.9 (3.4, 4.4)	5.4 (4.8, 6.0)	7.2 (6.4, 8.1)	
	PFC Sigma	393	8352	1.2 (1.0, 1.4)	2.6 (2.3, 2.9)	3.3 (2.9, 3.7)	4.7 (4.2, 5.2)	6.4 (5.8, 7.2)	

Figure 36: AOANJRR 2022 (pages 204 & 205) document similar overall trends for cemented Attune. It is unknown if the Attune tibial implants implanted after 2017 reflect the he original style or the S+ style tibial tray.

Based on review of FDA MAUDE complaint reports in 2013 and 2014 (through January 1, 2015), at least eleven incidents of loosening which occurred at the Attune tibial implant implant/cement mantle interface had been reported to the FDA (MAUDE database reports. According to Plaintiff's counsel in this case, the DePuy discovery documents indicate that surgeons complained to DePuy about cement debonding form the Attune cemented tibial baseplate which is at issue in this case, and that an internal investigation, led by Mark Heldreth, began at least by 2014. As a result, the newer version of the Attune cemented tibial baseplate, the S+ style, was likely in development beginning in about 2014, and concluded with the FDA clearance of the S+ version and its subsequent market release. At this time I have not reviewed documents that reveal the exact timing of the release of Attune S+ in Australia or UK. However the improved fixation of the tibial baseplate is described in an 2017 marketing brochure[P], and a US FDA 510(k) summary No. K170806 was submitted in March 2017 and cleared in June 2017.

Register data are based on few, but well-standardized and objective parameters such as revision rate. Revision rate is an essential, but not the only, parameter for assessing the quality of arthroplasty treatment. Subjective assessment of the outcome and the quality of life are without doubt of equal importance. However, it is considerably more difficult to cover these issues by means of a register.[139] In addition, many patients like suffer with pain and function loss without agreeing to revision. Thus the cement debonding of an Attune tibial baseplate may not be identified or revised in those patients.

Legal counsel for DePuy has stated in court that the exact style Attune cemented tibial baseplate that was used in Ms Sprafka is still being sold. It is my understanding that no data has been provided to Plaintiff's counsel to confirm how many of the style of Attune cemented tibial baseplates in question in this matter, are still being manufactured , sold and implanted.
No data concerning the following has been provided in raw or summary form:

- The number of implantations of the style of Attune cemented tibial baseplates in question;
- The number of implantations of the style of Attune cemented tibial baseplates in question implanted with HV cement vs standard or low viscosity cement;
- The number of revisions reported for the style of Attune cemented tibial baseplates in question, and associated revision rate;

[P] [DSUS/JRC/0517/2142(2) 08/2017 Attune S+ Technology]

- The number of revisions due to debonding reported for the style of Attune cemented tibial baseplates in question, and associated revision rate.

This information is not available in public Registry data.

The publically available Registry data is not specific enough to differentiate the reason for tibial loosening. Public Registry data is not specific enough to differentiate the style of Attune tibial baseplate (e.g. original style as used in Ms Sprafka or the improved cement adhesion version (Attune S+). A manufacture can request a more specific breakdown of data from the NJR and AOANJRR (Ad Hoc requests). DePuy is able to request ad hoc breakdowns for the revision of specific style of implants implanted in the AOANJRR and the UK NJR, for example. It may be helpful to review any Ad Hoc reports DePuy has obtained which depict the revision rate for loosening (and the rate of debonding if captured) for the original Attune tibial baseplate compared to the Attune S+ tibial baseplate in these registries. DePuy should know if the public Registry is based on the original Attune or the S+ Attune, or a combination. It might be helpful to understand the percentage of Attune S+ baseplates included in the public Registry statistics.

The failure data in the public Registry is simply not detailed enough, and is therefore unreliable relative to the issues at hand in this matter.

Tibia loosening at the cement-bone interface remains a common failure mechanism. However, Julie Sprafka's tibial implant did not loosen at the cement- bone interface. Failure should not initiate due to implant-cement interface debonding, as occurred in Julie Sprafka.

Risk Mitigation

A company that designs, manufactures, or offers any product for sale has a responsibility to protect people from hazards that may be present in their products.

Hazard - Potential source of harm
Harm - Physical injury and/or damage to health or property
Risk - Probable risk of occurrence of a hazard causing harm and degree of severity
Safety - Freedom from unacceptable risk of harm
Mitigation - To reduce or eliminate risk of hazard and to increase safety

The design process must take into account the types of actions that people make under reasonably foreseeable conditions of service, including intended use and reasonably foreseeable misuse. Hazards should be designed out of the product through engineering means. If the hazard cannot be eliminated, guards must be provided. In all cases in which the hazard cannot be eliminated or guarded against, clear and prominent warnings or instruction as to the dangers of the product must be provided. These are the three steps of the fundamental principles and rules of practice for safe and appropriate engineering of products. Hazard analysis and harm mitigation rests with the manufacturer.[140, 141]

The design process must take into account the condition of the patient/consumer by whom the device is intended to be prescribed/used. This has long been taught. The American Society of Mechanical Engineer's 1984 Publication, "Instructional Aid for Occupational Safety and Health in

Mechanical Engineering" [142] states:

> "There are six basic guidelines which a designer can apply in order to maximize the safety level of his products or manufacturing processes. The National Safety Council has published this list in descending order of effectiveness. One should rely upon the highest concept attainable, but if this is not possible, the very next one shown should be used.
>
> In brief these are:
> 1. Eliminate the hazard from the product or process by altering its design, material, usage or maintenance method.
> 2. Control the hazard by capturing, enclosing or guarding it at its source.
> 3. Train personnel to be aware of the hazard and to follow safe procedures to avoid it.
> 4. Provide adequate warnings and instructions in appropriate forms and locations.
> 5. Anticipate common areas and methods of abuse and take steps to eliminate or minimize the consequences associated with such actions.
> 6. Provide personal protective equipment to shield personnel against the hazard.
> 7. These six rules are interrelated and more than one can be used in a specific situation. For instance, training and warnings can often supplement machine guarding and the use of personal protective equipment."

The risk of cement debonding at the Attune tibial tray base plate –cement interface could have been significantly minimized by relatively simple, relatively inexpensive and well-recognized design improvements as previously itemized. (Design out risk of harm) Further risk mitigation could have been attained via appropriate surgeon training materials (instructions precautions and warnings).

Medical device manufacturers have a responsibility to characterize the mechanical performance of a device in typical and foreseeable worst-case clinically relevant conditions. In products like knee implants, where overload is both possible, and common under certain circumstances, the manufacturer has a responsibility to educate the users (surgeons, patients and other caretakers) concerning the device limitations including methods users can adopt to assure effectiveness and prevent injury from device overload, misuse, cement breakdown or debonding.

In addition the manufacturer of any medical device has the responsibility to do a well thought out and accurate design failure modes and effects analyses (FMEAs) and risk analyses to assure that foreseeable harms and related risks of that harm are mitigated.

Warnings and Precautions

Selected IFU text - [DEPATT_00130346/354]

> 'CONTRAINDICATIONS
> The following conditions are contraindications for total knee replacement:
> 1. Active local or systemic infection.
> 2. Loss of bone or musculature, osteoporosis, neuromuscular compromise or vascular deficiency in the affected limb in sufficient degree to render the procedure unjustifiable (e.g., absence of musculoligamentous supporting structures, joint neuropathy).

3. Severe instability secondary to advanced loss of osteochondral structure or the absence of collateral ligament integrity.
NOTE: Diabetes, at present, has not been established as a contraindication. However, because of the increased risk for complications such as infection, slow wound healing, etc., the physician should carefully consider the advisability of knee replacement in the severely diabetic patient.'

'CAUTION: The following conditions, singularly or concurrently, tend to impose severe loading on the affected extremity thereby placing the patient at higher risk of failure of the knee replacement:
1. Obesity or excessive patient weight.
2. Manual Labor.
3. Active sports participation.
4. High levels of patient activity.
5. Likelihood of falls.
6. Alcohol or drug addiction.
7. Other disabilities, as appropriate.
In addition to the above, the following physical conditions, singularly or concurrently, tend to adversely affect the fixation of knee replacement implants:
1. Marked osteoporosis or poor bone stock.
2. Metabolic disorders or systemic pharmacological treatments leading to progressive deterioration of solid bone support for the implant
(e.g., diabetes mellitus, steroid therapies, immunosuppressive therapies, etc.).
3. History of general or local infections.
4. Severe deformities leading to impaired fixation or improper positioning of the implant.
5. Tumors of the supporting bone structures.
Allergic reactions to implant materials (e.g. bone cement, metal, polyethylene).
7. Tissue reactions to implant corrosion or implant wear debris.
8. Disabilities of other joints (i.e., hips or ankles).
A higher incidence of implant failure has been reported in paraplegics and in patients with cerebral palsy or Parkinson Disease.
WHEN THE SURGEON DETERMINES THAT KNEE REPLACEMENT IS THE BEST MEDICAL OPTION AVAILABLE AND DECIDES TO USE THIS PROSTHESIS IN A PATIENT WHO HAS ANY OF THE ABOVE CONDITIONS OR WHO IS SIMPLY YOUNG AND ACTIVE, IT IS IMPERATIVE THAT THE PATIENT BE INSTRUCTED ABOUT THE STRENGTH LIMITATIONS OF THE MATERIALS USED IN THE DEVICE AND FOR FIXATION AND THE RESULTANT NEED TO SUBSTANTIALLY REDUCE OR ELIMINATE ANY OF THE ABOVE CONDITIONS.
The surgical and postoperative management of the patient must be carried out with due consideration for all existing conditions. Mental attitudes or disorders resulting in a patient's failure to adhere to the surgeon's orders may delay postoperative recovery and/or increase the risk of adverse effects including implant or implant fixation failure.
Excessive physical activity or trauma to the replaced joint may contribute to premature failure of the knee replacement by causing a change in position, fracture, and/or wear of the implants. The functional life expectancy of prosthetic knee implants is, at present, not clearly established. The patient should be informed that factors such as weight and activity levels may significantly affect wear.'

'ADVERSE EVENTS AND COMPLICATIONS
The following are generally the most frequently encountered adverse events and complications in total knee arthroplasty:
General
1. Early or late loosening, tibial subsidence, bending, cracking, fracture, deformation, or wear of one or more of the prosthetic components, often related to factors listed under WARNINGS AND PRECAUTIONS. Loosening may also occur due to improper fixation or positioning.

2. Early or late infection which may require removal of the implant and a subsequent arthrodesis.
3. Pain, dislocation, subluxation, flexion contracture, decreased range of motion, or lengthening or shortening of the leg, caused by improper positioning, looseness or wear of components.
4. Excessive wear of the polyethylene components due to intraoperative damage to the femoral component, loose cement and/or bone fragments, and/or high patient activity levels or weight.
5.Fractures of the tibia or femur. lntraoperative fractures are usually associated with revision surgery, deformity and/or severe osteoporosis. Postoperative fractures are usually stress fractures. Fractures can be the result of defects in the cortex due to multiple pin holes, prior screw holes, misdirected reaming, and/or inadequate or maldistribution of bone cement.
6. Cardiovascular disorders and thromboembolic disease, including venous thrombosis, and pulmonary embolus, and heart attack.
7. Tissue reactions, osteolysis, and/or implant loosening caused by metallic corrosion, allergy or wear debris or loose cement particles.
8. Myositis ossificans, especially in males with hypertrophic arthritis, limited preoperative range of motion and/or previous myositis. The incidence of myositis ossificans is increased with a history of prior surgery and in cases of infection.'

'Early Postoperative
1. Hematoma.
2. Delayed wound healing or wound dehiscence.
3. Varus-valgus deformity.
4. Subsidence associated with all poly components.
Late Postoperative
1. Inadequate range of motion due to improper selection or positioning of components, impingement and/or periarticular calcification.
2. Periarticular calcification or ossification, with or without impediment to joint mobility.
3. Patellar fracture as a result of excess tension or inadvertent intraoperative weakening.
4. Aggravated problems of the affected limb or contralateral extremity caused by leg length discrepancy.
The incidence and severity of complications in total and unicompartmental knee replacement are usually greater in revisions than primary operations. Common problems include placement of incision and lack of bone stock. Increased operative time and increased incidence of infection, pulmonary embolism and wound hematoma can be expected with revision procedures.'

In the Attune IFU and in the surgical technique there are no warnings or precautions concerning tibial implant-bone cement interface debonding or methods surgeons can use to mitigate the potential for implant-bone cement debonding. Special cementation instructions such as: " Make sure the baseplate is clean and dry when applying the bone cement to the surface. Only apply bone cement during the optimal working time ('sticky' or 'tacky' phase) when adhesion is maximal. Optimal adhesion time varied for low , medium and high viscosity cements. Refer to the bone manufacturer's instructions for optimal working and metal adhesion timing." Should have been provided by DePuy.

The DePuy Attune knee is susceptible to cement debonding. It is more sensitive to cementation technique than the PFC Sigma predecessors, and to the Attune S+. Due to the inadequate cement fixation interface in the Attune tibial baseplate, the surgeon's work flow and cement application timing (cement technique) is MORE important to mitigate this debonding risk. Tips to mitigate this risk are not present it the product information provided when the implant was launched. The risk of cement debonding was not communicated to surgeons to allow them to make informed implant selection choice and and cement application decisions.

A circa 2017 document [DSUS/JRC/051 7/2142(1) 08/2017] refers to two DePuy documents focused on cementation techniques.

1. Dennis D.A., MD, Kowalski R., PhD. Cement Technique in Total Knee Arthroplasty. *DePuy Synthes Companies White Paper.* 2015. DSUS/JRC/1114/0581.
2. Guidance for Cementing Primary Total Knee Replacements. *DePuy Synthes Companies.* 2015. DSUS/JRC/114/0580

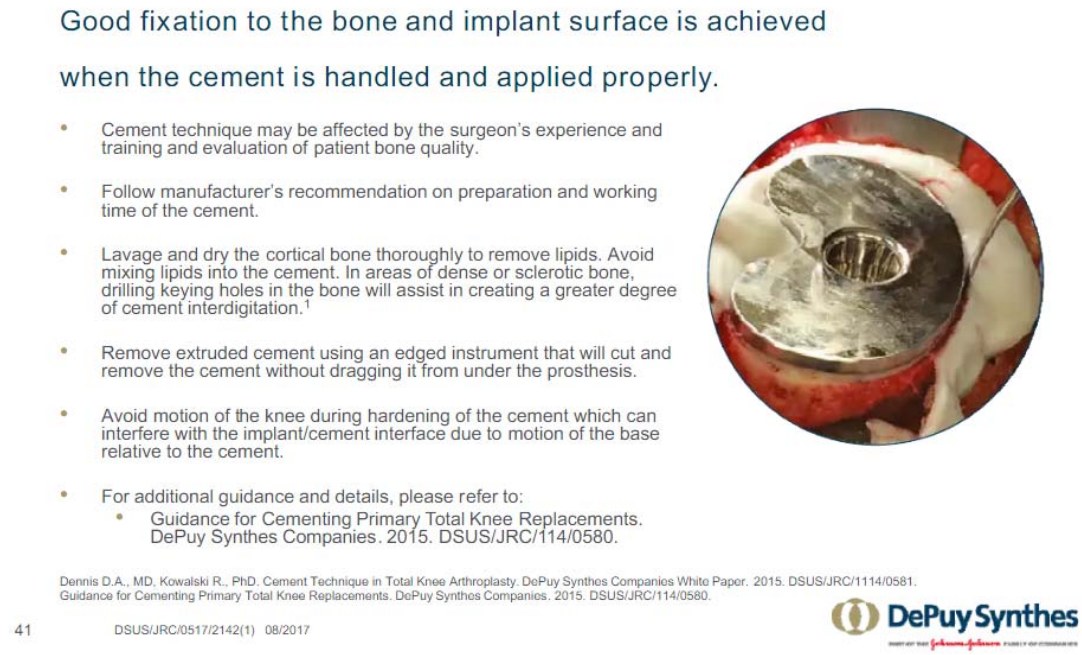


Figure 37: Image from DePuy Brochure [DSUS/JRC/051 7/2142(1) 08/2017].

The Dennis and Kowalski white paper indicated (DePuy in mid 2015) stated, among other things,

> "Failure at the cement-bone interface may appear as radiolucent lines and is usually attributed to poor penetration of the cement into the bone. Failure at the cement-implant interface may be due to the poor interfacial strength of the cement to the implant."
>
> "…The cement then reaches its dough state, where the surface of the cement becomes less sticky even though the main body of the cement remains sticky. This phase is usually known as the working phase of the cement."
>
> "Applying cement directly to the implant at the beginning of the working phase improves the mechanical interlock with the implant. If the cement is used too late in its working phase, it will not maintain a good micro-interlock with the bone or mechanical interlock with the implant."
>
> "It is important to store and prepare the powder and liquid at normal operating room temperatures. Some surgeons pre-warm the powder or liquid beyond the temperature range stated in the IFU to reduce the setting time of the cement. This fundamentally alters the handling characteristics of the cement and is not recommended. It not only reduces the

setting time of the cement, but also can have a significant effect on reducing the working phase. This, in turn, will increase the risk of the cement being used too late in its working phase."

"Note: During the end of the working phase and until the cement has fully cured, it is recommended that the implant is not disturbed, and in the case of TKA, is kept under pressure by keeping the knee in full extension. Hyper-extending and hyper-flexing of the knee before the cement has fully hardened should be avoided, as it may alter the flow of cement and disrupt the cement mantle or pull the cement away from the underside of the tibial component. If the cement separates from the implant during working phase, it is unlikely to reseat and form a strong mechanical interlock with the implant and could potentially lead to loosening at the cementimplant interface."

While the global rate of aseptic loosening was reported by DePuy in 2017 to be 1.5% at 10 years, the aseptic loosing rate in the literature in a case study involving was 1.3% at 2 years, and all of those loosening were due to debonding at the tibial implant-cement interface. (Torino et al[143]) DePuy was aware of the harms associated with aseptic loosening of knee implants, providing data in brochures in 2017.

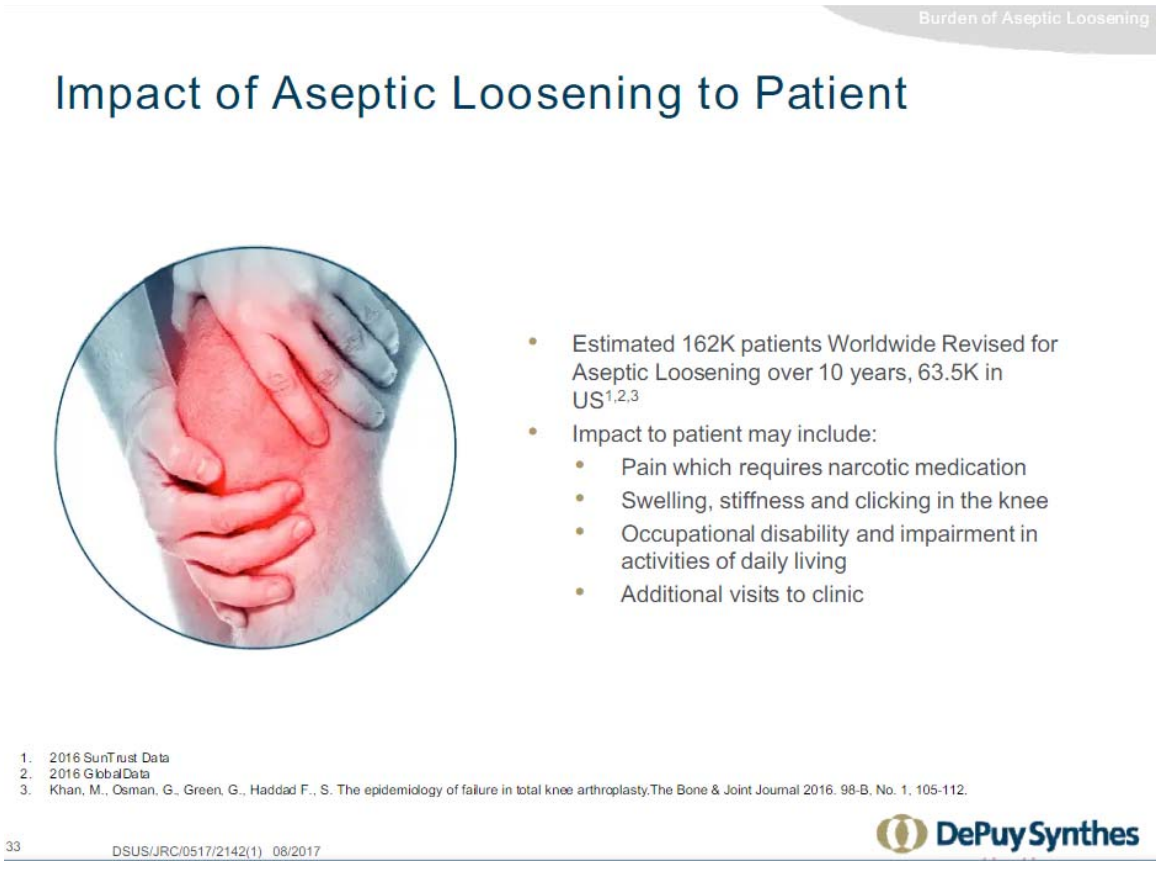


Figure 38: Image from DePuy Brochure [DSUS/JRC/051 7/2142(1) 08/2017].

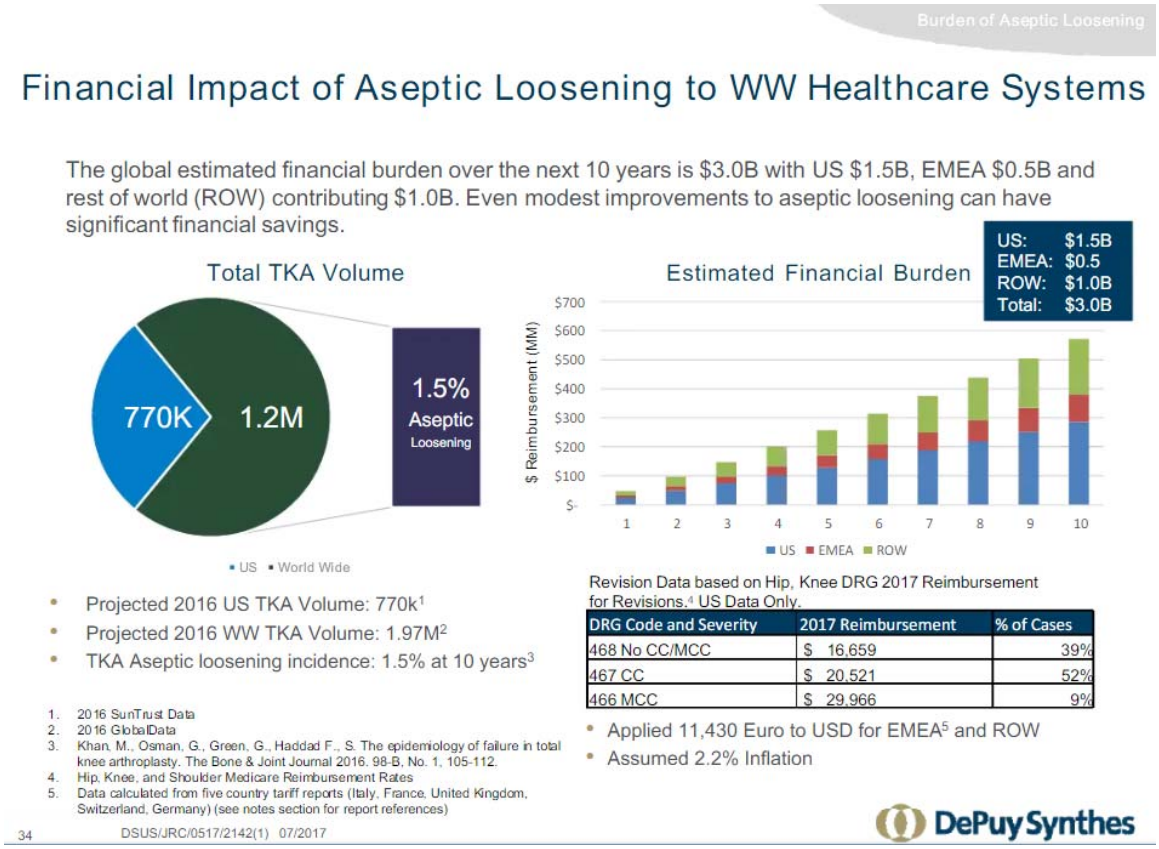


Figure 39: Image from DePuy Brochure [DSUS/JRC/051 7/2142(1) 08/2017].

The fact that the Attune implants were experiencing loosening due to cement debonding (as opposed to the loosening understood to be due to insufficient cement interdigitation, bone overload or osteolysis), and specific instructions to mitigate this risk was critical. Surgeons needed to know to apply cement to the metallic surfaces of the tibia baseplate first, and in a sticky phase, prior to or early in the working phase. The also needed to know not to move the knee until the tibial baseplate cement had cured. A reasonable and responsible manufacturer concerned about patient safety would have assured that this critical information was communicated to surgeons implanting Attune to mitigate the reported debonding failures. Such communication could have been done using one or more mediums such as salesforce verbal communication, recall of older surgical techniques and replacement of new techniques with additional warnings, precautions and instructions, direct contact ('dear doctor" letters or direct surgeon e-mail), J&J web page links. Furthermore, a reasonable and responsible manufacturer concerned about patient safety would have discontinued Attune baseplates once the Attune S+ baseplates were cleared by regulatory bodies and sufficient quantities were manufactured to support ongoing demand for Attune TKAs.

Standards Compliance

ISO 13485 (2003) is an international standard, published in 2003, that represents the requirements for a comprehensive management system for the design and manufacture of medical devices. It supersedes earlier documents such as EN 46001 and EN 46002 (both 1997), the ISO 13485 published in 1996 and ISO 13488 (also 1996). While it remains a stand-alone document, ISO 13485 is generally harmonized with ISO 9001(2000). ISO 9001 requires the organization to demonstrate continual improvement, whereas ISO 13485 requires only that they demonstrate the quality system is implemented and maintained.

ISO 14971 is the risk management standard for medical devices. The U.S. FDA and Health Canada have both recognized the 2007 version of this international standard, but in 2012 the European Commission identified that this specification deviates from the Essential Requirements of the European Medical Device Directives. In order to comply with the EN ISO 14971:2012 version of the risk management standard, companies need to implement risk controls for all risks, regardless of acceptability. Unfortunately, many companies choose arbitrary thresholds for acceptability of risk. Instead of relying upon benchmarking or risk/benefit analysis, companies established that a policy that all risks must be below a quantitative value. *All risks, regardless of their dimension, need to be reduced as much as possible and need to be balanced, together with all other risks, against the benefit of the device.* The risk/benefit analysis should consider not only the benefits to patients and the risks of using the device, but the analysis should also consider relative benefits of using other devices. Furthermore, unless the risk controls would not reduce risks further, or the risk controls are incompatible with other risk controls. Risk control options should never be ruled out due to cost. The following wording for implementation of risk control options in the new proposed second Essential Requirement is below:

> *"The manufacturer shall apply the following principles in the priority order listed:*
>
> *a. identify known or foreseeable hazards and estimate the associated risks arising from the intended use and foreseeable misuse;*
>
> *b. eliminate risks as far as possible through inherently safe design and manufacture*
>
> *c. reduce as far as possible the remaining risks by taking adequate protection measures, including alarms; and*
>
> *d. provide training to users and/or inform users of any residual risks."*

The new proposed Essential Requirements also include numerous examples of how the manufacturing processes must ensure proper safety.[144]

DePuy filled out an Essential Requirements Checklist indicating the applicability of Essential requirement 1 and 2. DFMEA indicated that adequate cemented fixation required (femur) [DEPATT 00130245, DEPATT 00126075]. The only testing listed is tribal trail axial pull out and sawbones evaluation. [DEPATT 00130442/443]

I noted that, in the Summary DFMEA and Risk Mitigation Activities, (SEP-100, Revision B, Appendix D DVA-103614-RMR Rev 5) the tibial base -cement interface loosening (debonding) and the cement -bone interface breakdown under in vivo loading was not deemed a severe hazard event though loosening of the implant is the most common reason for revision and failure complaints of the non-infected TKA. [DEPATT 00136179; 00136182/184, 00136200/201, 00136236/238, 00136338/339]

DePuy wrote [DEPATT 00136180]:

"Premature implant failures would cause an early revision for the patient. This is a severity level of ten and could be caused by incorrect material selections or implant geometry on both the femoral and tibial insert components."

I noted that in this assessment tibial base cement interface fixation strength was not mentioned.

In this same document, DePuy did note that there was a known Potential for Use Errors Triggered by Design Flaws such as Confusing or Missing Instructions for Use or Judgement Errors. [DEPATT 00136188, 00136343]

Failure Modes listed [DEPATT 00136189, 00136243/244, 00136344 included, among others (1) Unexpected loss of Mechanical Integrity (including unintended disassembly or loosening of parts); (2) Deterioration of function; (3) Fatigue failure. Concerning these failure modes DePuy noted that they had considered the failure modes in the DFMEA, and had completed fatigue testing. However, I noted that the testing mode used to assure that the implant-cement fixation interface remained durable was a quasi-static tension test. This test was inadequate to assure that this interface would survive in vivo for numerous reasons (previously described)

(a) In vivo loading includes tension, shear and compression. Because the tibio-femoral contact interface locations change (translates and rotates) the fixation interface is subjected to compression on one side and lift off in the opposing side as well as shear and torsion. Rocking can occur in the A/P or M/L direction. The torsion and rotation also contribute to the shear and compression/tension rocking in vivo. Bone cement is stronger in compression, and weaker in shear and tension. DePuy's design team ultimately failed to take into account the rocking and shear forces and combined loading at various time points, even though rocking and cyclic loading was discussed in the team meetings with surgeon and was also mentions in kinetics and kinematics (roll back and screw home mechanism, disparate M/L loading) portions of the document entitled "Total Knee Replacement - Biomechanics and Device Design Document" prepared for DePuy Orthopaedics Inc. by David Fitzpatrick and dated February of 2006. [DEPATT 00129870/945]
(b) When it established the geometry features for Attune tibial baseplate there was a lack of undercuts to physically capture cement and DePuy chose to use of a smoother surface feature (60 grit blast vs 20 grit blast) than found in the predecessor and clinically successful MBT tibial baseplate interface.
(c) DePuy failed to complete implant -cement fixation characteristic testing following cadaver testing to understand the effect of the new fixation geometry including surface finish changes compared to predicates. DePuy also failed to investigate and provide cementation techniques guidelines for use of the different types of bone cement commercially available in 2011 when the Attune was launched. (low, medium and high viscosity with or without antibiotics). The higher viscosity bone cement DePuy recommended each have different times for optimal implant adhesion.
(d) When the establishing the performance requirements and the test methods to assess the tibia base plate-cement fixation there was no consideration of the weakening of the cement-implant interface in vivo due to hydrolysis.

Based on my review of the FMEAs DePuy did not meet Essential Requirements 1 and 2 relative to the risk of tibial tray bone cement fixation breakdown (debonding) and loosening. This is due to the design defects in the tibial tray cement attachment interface features and the company's failure to detect and mitigate the tibial tray-cement interface break down risk. The tibial tray

cement pocket design features are deficient and resulted in early debonding, loosening, wear debris, local adverse tissue responses and pain in Julie Sprafka, which resulted in the need for her knee implant revision surgery.

Patient Demographics

In the 1970s and 1980s when the ASTM and ISO standards for hip and knee testing were initially developed, the typical joint implant recipient was an elderly, retired and minimally active individual, possibly returning to occasional golf, walking or swimming. However today's patients are significantly more active. Many are still working. Some are engaged in higher leg impact sports such as jogging, basketball, racquetball and tennis. Others are returning to work and recreational activities requiring lifting, carrying and squatting.[145]

Total joint replacement (TJR) should be tested in realistic environmental conditions including reasonably anticipated forces and moments (stress levels) consistent with today's patient population[146,147,148,149,150,151,152,153,154] reasonable ranges of implant positioning, and the chemical/electrochemical environment. For total knee systems, a comprehensive knee simulator study, which includes many common daily activities, may be warranted if the design has new features with increase the risk of failure due to fatigue, wear or premature cement mantle breakdown or debonding or other device dissociation.

Longevity

The overall goal of total knee arthroplasty (TKA) or total knee replacement (TKR) is to relieve pain and restore functional movement. Early debonding of the PMMA cement from the tibial tray base-plate interface should not have occurred in Julie Sprafka. The overwhelming majority of total knee implant last 15 to 20 years or more.

The Australian Orthopaedic Association annually releases a report regarding primary and revision hip and knee procedures. Since the United States do not currently have a joint registry, the Australian Registry[155] is often utilized. In the 2017 Australian Orthopaedic Association National Joint Replacement Registry (AOA NJRR), Supplemental Report for Cement in Hip and Knee Arthroplasty, the cumulative incidence of revision of cemented knee implants for loosening is less than 5% at 15 years. The overall cumulative revision rate at 15 years for all causes is 8%.

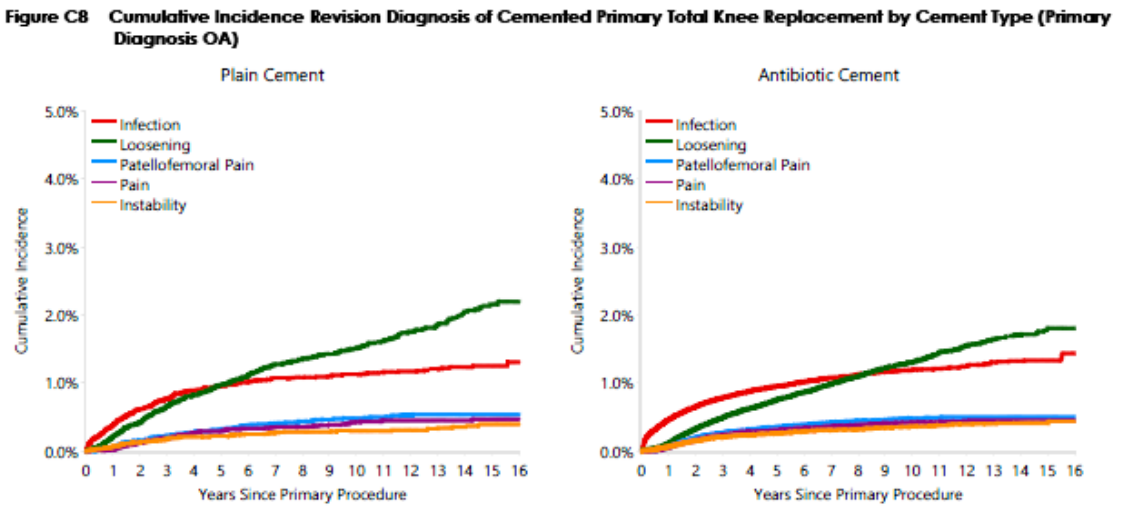


Figure 40: In the 2017 Australian Orthopaedic Association Registry, the cumulative incidence of revision of cemented knee implants for loosening is less than 5% at 15 years.

The Specific Hazard in this Incident

Julie Sprafka was only 55 years old at the time of her primary right knee surgery. She was at most moderately active due to her ongoing knee pain. Julie Sprafka was exposed to hazards of premature implant failure and chronic pain leading to a revision total knee surgery. In addition to the risks of surgery, including but not limited to infection, embolisms and anesthetic complications, revision total knee surgeries generally have poorer functional, patient satisfaction and quality of life outcomes. The combination of these hazards and exposure made the Attune cemented fixed bearing tibial baseplate component unreasonably dangerous and unsuitable for its intended purpose.

Reasonable Use

Julie Sprafka was a 59-year-old x 5'6" tall female who weighed about 214-220 lb (BMI ~35) when her total knee procedure failure was diagnosed in mid 2020 due to loosening. Debonding of the PMMA bone cement from her Attune tibial baseplate was identified during her revision surgery. The debonding is consistent with her chronic pain, the diagnosed loosening, the bone loss at revision and the loss of normal function of her right leg until she recovered from her revision surgery. She did not act or react improperly in a manner that caused her injury.

G. FINDINGS

It is my understanding that Dr Saterbak's deposition is pending , that additional 30b(6) depositions of DePuy staff are pending, that Plaintiff's counsel has received additional discovery documents and that counsel may provide for my review. I may have additional comments, opinions, or adjustments to these findings in supplement form, upon review of additional case materials.

Within the bounds of reasonable engineering and scientific certainty, and subject to change should additional information become available, it is my professional opinion that:

1. The Attune tibial baseplate, which was used in Julie Sprafka, has a clinically documented risk of early aseptic loosening due to cement interface debonding. In a case study reported in the literature, the 2-year aseptic revision rate due to debonding approximated the global 10-year aseptic loosening rate DePuy documented for total knees. The design team intentionally left off baseplate undersurface cement capture features known to have durable and improved cement interface fixation in predecessor devices. Moreover, the cement fixation interface was not evaluated under reasonably foreseeable operative room and in vivo physiologic loading conditions prior to design freeze during development or global launch.

2. The cement fixation interface surface of the tibial implant baseplate in the Attune fixed bearing tibial base plate is defective in design. There are no macro lock features, and given this, the surface is too smooth. The shallow cement pocket with radius'd edges offer little resistance to shear forces at the cement-implant interface. Given that the Attune tibial baseplate had no substantial mechanical capture feature to secure the bone cement, the specification of a 60-grit blast surface finish on the CoCr baseplate cement fixation surface, with an R_t of 7μm min or an Ra equivalent minimally around 1.6 and up to a the range of about 2.5 to 3.5μm, is a design defect. The Attune tibial baseplate design defects were exacerbated by failure to provide cementation instructions to lessen the cement interface debonding risks.

3. Due to cement debonding from the defectively designed Attune tibial baseplate, Julie Sprafka was exposed to hazards of premature implant failure and pain for over 5 years, leading to a revision total knee surgery. The combination of these hazards and exposure made the Attune cemented fixed bearing tibial baseplate component unreasonably dangerous and unsuitable for its intended purpose.

4. Reasonable design alternatives which include geometry changes to provide macro-lock fixation at the cement-metal tibial base plate interface could have been incorporated and reasonable design alternatives incorporating one or more of macro lock options were (and are) available from other manufacturers. In addition to macro geometry changes, a rougher surface finish at least equivalent to a previous DePuy knee tibial implant, MBT, could have been selectively specified for the baseplate undersurface. (i.e. the stem could have had a smoother finish. During blast cabinet processing, masking to achieve different surface finishes on the baseplate undersurface, verses the stem, and does not add substantial cost to the implant).

5. The surgical techniques and brochures that the DePuy sale representative provided to or discussed with Dr Andrea M. Saterbak have not been provided for my review. The training materials available in the 2011- early 2015 period, as reviewed to date, do not provide adequate instructions to minimize the risk of cement debonding in the tibial implant. For example, the following subject matters were not identified in the training materials:

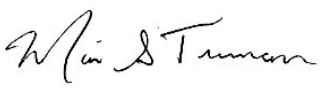
a. Moving or applying force to the tibial implant after impaction but prior to cement hardening can lead to interface contamination and debonding;
b. Interface contamination can lead to tibial tray debonding;
c. Apply cement to both the implant and the bone surface.
d. Late application of PMMA cement to the implant metal surfaces can lead to cement debonding, while application at the tacky stage can improve cement adhesion to the metal substrate. Apply the tibial baseplate undersurface cement early while in the cement is still in the 'sticky' or 'tacky' phase and apply the cement to the bone in the doughy phase when the viscosity is sufficient to counter blood flow. Pressurize the cement interface while the cement is hardening.
e. Vacuum mixing and appropriate bone surface preparation with lavage are necessary to assure optimal cement mantel and cement into the tibial bone;

At this time this is assumed that the sales representative for Dr Saterbak did not discuss the documented failures of the Attune baseplate and the need to follow the new warnings and instructions provided in the DePuy guide entitled " Cement Technique in Total Knee Arthroplasty DSUYS/JRC/114/0580 (published 06/2015) to help mitigate the risk of debonding when implanting Attune TKAs.

6. Based on review of the operative report, other medical records, X-rays/radiology reports, the explants and DePuy discovery documents, Dr Andrea M. Saterbak implanted the Attune tibial baseplate in Julie Sprafka per the instructions for use and per the surgical technique made available by DePuy. She did not alter or change the tibial baseplate during installation. The Attune tibial baseplate was implanted in Ms Sprafka without substantial change in the condition in which it was manufactured and sold.

7. Julie Sprafka did not act or react improperly in a manner that caused her injury.

8. A cemented TKA implant manufacturer has a duty to assure that the design of the cement-implant interface is robust enough to withstand in vivo loading. Clinical failure should not initiate due to implant-cement interface debonding as occurred in Julie Sprafka. The defects in the Attune fixed bearing cemented tibial tray base plate resulted in the PMMA bone cement debonding and, from a biomechanical engineering standpoint, this was a proximate cause of Julie Sprafka's aseptic implant loosening, pain and function loss which resulted in the need for her revision surgery.



Mari S. Truman, M.S. P.E.
Products Liability, Orthopaedic Medical Device & Injury Biomechanics Expert
Ohio License # 69075

APPENDIX A – MATERIALS CONSIDERED

1. Julie Sprafka including ,among other things ,the operative report for her right knee TKA procedures, office and clinic notes, PT records, selected radiology results reports; SPRAFKA 000015-SPRAFKA 000247;
2. Complaint and Injury Demand, Julie Sprafka, Plaintiff, v. DePuy Orthopaedics, Inc., an Indiana Corporation and Medical Device Business Services, Inc., an Indiana Corporation;
3. Answer of Defendants DePuy Orthopaedics, Inc, and Medical Device Business Services to Sprafka Complaint and Affirmative Defenses file 09/24/2021;
4. Responses to Medical Device Business Services, Inc.'s (MDBS's) First Set of Interrogatories to Plaintiff;
5. Plaintiff's Responses to MDBS's First Requests for Production of Documents;
6. Medical Device Business Services, Inc.'s Objections and Responses to Plaintiff's Requests for Admissions;
7. Defendant's Response to Plaintiff's First Set of Requests for Production of Documents;
8. Defendant's Response to Request for Production, Bates Nos DEPATT 127671-127933; DEPATT 127934 - 128814; DEPATT 128815 - 129734; DEPATT 129735 - 130734; DEPATT 130735 - 131732; DEPATT 131733 - 132719; DEPATT 132720 - 133710; DEPATT 133711 - 134594; DEPATT 134595 - 135590; DEPATT 135591 - 136570; DEPATT 136571 - 137392; DEPATT 218307 - 219304; DEPATT 219305 - 220249; DEPATT 220250 - 221237; DEPATT_PROD002_DAT.XLS;
9. Exhibit 2 from Diabla Responses and the chart below (Lists of responsive Bates No.);
10. My February 16, 2023 visual inspection of the DePuy Synthes Attune femoral and tibial devices explanted from Julie Sprafka including the 184 color photographs taken by me memorializing my visual inspection;
11. My March 17, 2020 visual inspection of the DePuy Synthes Attune femoral and tibial devices explanted from Regina Dibala including the 190 color photographs taken by me memorializing my visual inspection;
12. MAUDE reports summary 2010 to January 2020 (provided by attorney);
13. ASTM F2777-10 Standard Test Method for Evaluating Knee Bearing (Tibial Insert) Endurance and Deformation Under High Flexion;
14. ASTM F3141-15 Standard Guide for Total Knee Replacement Loading Profiles;
15. ASTM F1223-14 Standard Test Method for Determination of Total Knee Replacement Constraint;
16. ASTM F1800-12 Standard Practice for Cyclic Fatigue Testing of Metal Tibial Tray Components of Total Knee Joint Replacements
17. ASTM F1814-15 Standard Guide for Evaluating Modular Hip and Knee Joint Components;
18. ASTM F451-16 Standard Specification for Acrylic Bone Cement;
19. ASTM F2083-12 Standard Specification for Knee Replacement Prosthesis;
20. DePuy Synthes Joint Reconstruction Brochures
    - DSUS/JRC/0514/0162 Attune Knee System stabilityinmotion
    - DSUS/JRC/0714/0314 Attune Knee System AOX Antioxidant Polyethylene
    - DSUS/JRC/0517/2142(2) 08/2017 Attune S+ Technology
21. Medical and Scientific Literature as Referenced in this Report.

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APPENDIX B - FORCES ON THE IMPLANTED KNEE

Peak loads during walking are typically between 1x and 3x body weight, but can be up to 4x body weight. Stumbling, stair ascent and descent, and chair rising typically apply peak forces between 3x and 8x body weight.[156,157,158,159,160,161,162] Load directions and magnitudes vary with activity and joint position evaluated.

Activity Levels: The number of cycles active patients apply to their hip and knee joints is well known.[163,164,165,166,167] Active total joint arthroplasty patients can average up to about 9688 steps per day, for a combined average of 3.54 million steps per year (range of .438 to 12.96 million steps per year).[168,169,170] Many active patients receiving total hips take over 3.5 million steps per year. Some also climb over 264-stair steps per day (96360 steps per year).[171] Assuming 1 walk cycle is 2 steps (1 step per leg), 3.54 million steps is 1.77 million cycles per leg. A hip or knee simulation of 10 million cycles, including about 300,000 stair climbs equates to less than 6 years of walking in these more active patients. More recently, Bennett et al[172] measured the activity level of their hip patient population in Northern Ireland. The patients' average steps per day ranged from 1005 to 13366 steps per day or 0. 37 million to 4.88 million steps per year, (or 2.44 million cycles per leg per year). 55 to 69 year olds averaged about 4873 to 4892 steps per day or about 1.78 million steps per year (.89 million cycles per year). NOTE: 10 Million cycles is equivalent to less than 6 years in an "active" patient. ASTM F3141-15 (now 2017) Standard Guide for Total Knee Replacement Loading Profiles suggests that 5% of the cycles should be stair ascent, 5% for stair descent and 1% for chair rise for the average patient.

Growing attention on the functional outcome of a total knee arthroplasty (TKA) has shown that many patients experience limitations when attempting to perform high demand activities considered normal for age-matched peers. This is primarily because of knee symptoms. For the

TKA patient, "high demand" activities are typically those imposing impact loads on the knee and/or those requiring extreme range-of-motion. In practice, activities leading to apprehension and discomfort following TKA more typically involve instability of the joint, in which significant transverse or torsional forces are applied with relatively low joint compression forces. Under these conditions, normal muscle contraction is accompanied by a shift in the relative positions of the bones. This occurs to maintain the balance of external forces as well as the internal restraints provided by the ligaments and the articular surfaces. [173]

Under more severe shear loading, the base-tray cement bond is more highly stressed, especially in situations with greater soft tissue laxity where there is greater AP translation of the contact location.

Many TKA patients experience limitations when attempting to perform "high demand" activities, which are typically those imposing impact loads on the knee or those requiring extreme range-of-motion. In practice, activities leading to apprehension and discomfort following TKA more typically involve instability of the joint, in which significant transverse or torsional forces are applied with relatively low joint compression forces. Such activities include stair-descent and walking on sloped or uneven surfaces. Under these conditions, normal muscle contraction is accompanied by a shift in the relative positions of the bones. This occurs to maintain the balance of external forces as well as the internal restraints provided by the ligaments and the articular surfaces.

Patients must compensate for the inherent instability of the knee prosthesis by varying the force of contraction of antagonistic muscle groups crossing the joint, most commonly the quadriceps and hamstring muscles. For example, Borque et al[174] have shown that quadriceps contraction affects knee AP stability during stair descent. Contraction restores the neutral femoral AP position on the tibia during stair descent and causes slight external rotation. Though this reduces subluxation of the femur in response to loading, the increased demand on the musculature may lead to pain and/or fatigue.

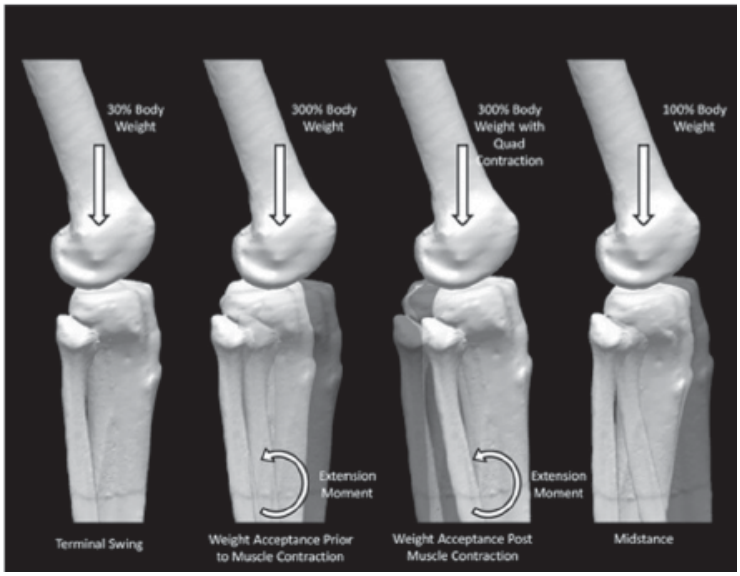

Figure 41: The phases of stair-descent as simulated during experimental testing. [175]

Researchers in Germany(Bergmann et al)[176,177,178] and the USA (D'Lima et al) [179, 180] have used instrumented total knee implants to measure the loads transmitted to the total joint implants during various activities., both typical and more strenuous. Kutzner and Bergmann[181] noted that the knee joint is highly loaded during daily life. In general, resultant contact forces during dynamic activities were lower than the ones predicted by many the mathematical models, but lay in a similar range as measured in vivo by others. Average peak resultant forces, in percent of body weight, were highest during stair descending (346% BW), followed by stair ascending (316% BW), level walking (261% BW), one legged stance (259% BW), knee bending (253% BW), standing up (246% BW), sitting down (225% BW) and two legged stance (107% BW). Peak shear forces were about 10–20 times smaller than the axial force. Resultant forces acted almost vertically on the tibial plateau even during high flexion. Some of the observed load components were much higher than those currently applied when testing knee implants. For example: The data confirms previous that the international standard protocol for wear tests of tibial inserts underestimates the axial torque Mz. Whereas a peak-to-peak moment of 7Nm is defined in the ISO standard (ISO14243-1, 2002) typical peak-to-peak moments of 15Nm were measured, with individual values of up to 19 Nm and an absolute range of even 29 Nm. The signs of the axial torque and all the other load components change within each load cycle during most activities. This is detrimental for bone-implant interface stresses and polyethylene wear and should be considered when testing knee implants.

Others have evaluated wear characteristics of TKAs under several activities of daily living such as stair descent, stair ascent and rising from a sitting position. For example, Benson et al,[182] (2002) evaluated the wear characteristics of the NK II device. If half the number of stair steps were assumed to be stair descent and the increased number of walking steps per clay were taken into account, a wear test simulating an average year of *in vivo* use should include at least 1.1 million walking cycles (or 11 M cycles per 10 years) and 23 913 stair descent cycles (or 2.39M cycles for 10 years). An equal number of stair ascent cycles should also be included, and other activities such as rising from a seated position might be incorporated as well (reported as 47 per day, or 17 155 per year, or 1.72 M per ten years). Considering this 15.11 M cycles or greater are needed to reflect 10 years of activity.

George Bergmann started in vivo measurement of dynamic 3D joint load vectors in 1979 and founded the OrthoLoad database, which is a free public database that supplies numerical load data and videos, which contain load-time diagrams and synchronous images of the subject's activities. Additional comprehensive data was, and is, provided to industry sponsors.[Q]

[Q] The OrthoLoad web site, http://www.orthoload .com, has been available for over 8 years.

The OrthoLoad database contains means and peak forces and moments applied at the tibio-femoral joint of a knee prosthesis for various activities of daily living such as walking, stair ascent and descent, jogging, standing up, and knee bends. Mean results for lower and higher weight patients are presented, with higher patient weights being defined as 100 kg (220.5 lb) in this work. For the knee moments recorded were in the range of about 186 to 478 in-lb (21 to 54 Nm) for 100 kg (220.5 lb) patients. The forces and moments are proportionally greater for heavier individuals.

Patient Weight: Peak forces during ambulation on lower extremity implants are approximately proportional to a multiple of body weight. Since today's patients are generally heavier, with many weighing above 200 lb, and some weighing up to 300 lb or more, the design and performance specifications for the implant and the implant - bone interface in these heavier patients must take these higher forces into account.

Table 3

220.5 lb subjects		
	Resultant Moment (in-lb)	Resultant Force (lb)
walking	407.1	809.3
stand up	203.6	843.0
sit down	212.4	899.2
jogging	477.9	1169.0
stairs down	420.4	933.0
stairs up	398.3	1034.1
knee bend	185.9	798.1

100 kg subjects		
	Resultant Moment (Nm)	Resultant Force (N)
walking	46	3600
stand up	23	3750
sit down	24	4000
jogging	54	5200
stairs down	47.5	4150
stairs up	45	4600
knee bend	21	3550

Population Shift – Heavier, Younger and more Active Patients

Note that current American Society of Testing and Materials (ASTM) and International Standards Organization (ISO) performance recommendations for consensus standard tests for total joint implants are based on lighter weight and less active patients of the 1970s. In the early knee simulations the test model subjects specimens to dynamic cycling combined under 2300 N *(517 lb)* compressive force (3 times body weight), 40 Nm varus moment, 36 Nm hyperextension moment and 10.8 Nm internal rotational torque. The load and moment values were based on the values described in the literature for level walking in this lighter weight patient population.

The standard, however, recommends that requirements be adjusted for different patient populations. Thus, the listed performance requirements do not reflect the use of total knee implant assemblies under many reasonably foreseeable cyclic forces (direction vectors, or magnitudes) commonly applied by higher demand patients (active and/or heavier patients) during manual labor jobs (work) and sport activities.

The loads placed on total knee (and hip) implants in heavier and in more active patients are also significantly higher than the loads specified in the standard hip (femoral stem) simulation test specification, ISO 7206.[183] (ISO 7206 applies a peak load of 2.3 kN or 517 lb.) To reduce this

problem a revised ISO standard should introduce a classification of hip prostheses, fixing different minimum requirements for endurance strength. Hip and knee stems which are designed to be implanted in heavy patients should be tested at higher load than the stem suitable for thin patients. What is critical in the definition of a fatigue test is the simulation of the different loading conditions that stress an implant. The body weight, the joint geometry and the daily activities of the patient affect the joint load. Forces in the range of *at least* 3 to 5 times body weight (BW), and preferably 7 times BW need to be considered in a fatigue test of stems to ensure sufficient implant strength. Furthermore the test method used to evaluate the endurance of a stem should include physiologically relevant loads with include the known levels of both compression and bending.

Table 1: Body Weight (BW) & Magnifiers

BW (lb)	3X BW (lb)	5X BW (lb)	7X BW (lb)		BW (kg)	3X BW (N)	5X BW (N)	7X BW (N)
155	465	775	1085		70.3	2068	3447	4826
220	660	1100	1540		99.8	2936	4893	6850
250	750	1250	1750		113.4	3336	5560	7784
350	1050	1750	2450		158.8	4671	7784	10898

It was foreseeable that a person weighting between 214 lb and 220 lb, and occasionally much greater, would have total knee surgery.

Studies have shown that obesity is one of the influencing factors associated with OA. International standards citing differentiations between “sub-groups” within the obesity categories are:

under 18.5 (underweight);
18.5–24.9 (normal weight);
25.0–29.9 (overweight);
30.0–34.9 (obese, class I);
35.0–39.9 (obese, class II);
40.0 and higher (obese, class III).

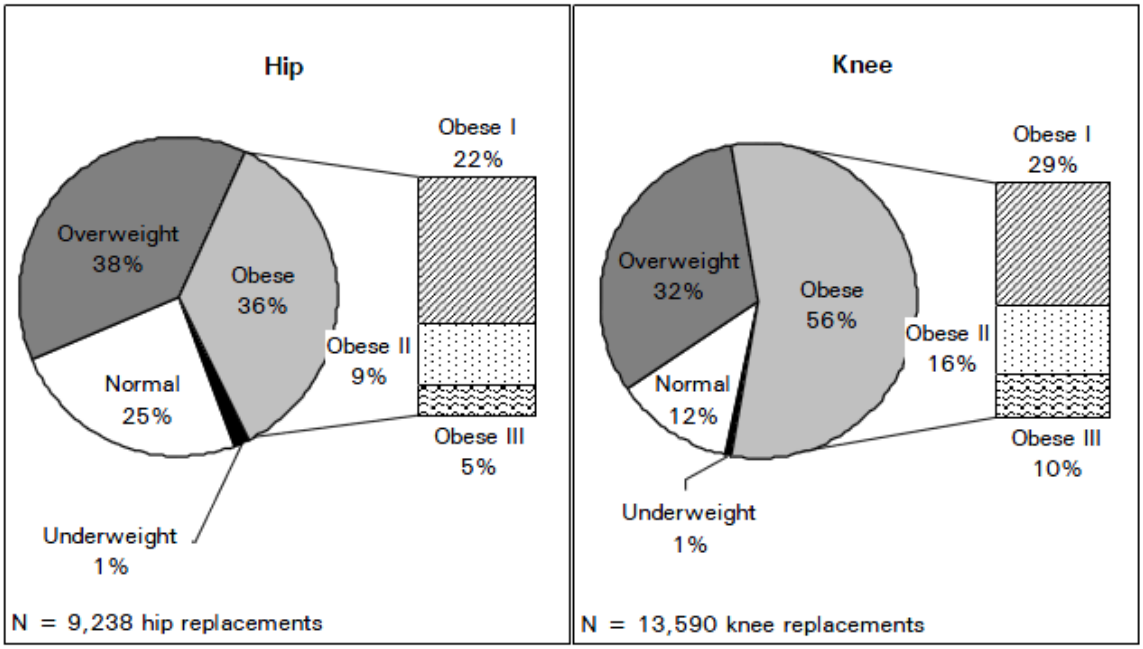

Figure 42. Hip and Knee Replacement Recipients by BMI Categories, CUR, 2005–2006.[184]

For hip and knee replacements, patients classified as belonging to the obese class I category represented the highest proportion of recipients in Canada in 2005–2006 (22% for hip and 29% for knee) (**Figure 42**). About 5% of THA recipients in Canada in 2005-2007[185] were in obesity class III. Trends are similar in the USA. For example, in 1997 Heck et al[186] reported that the mean TKA patient population (in Indiana) was obese (Mean BMI 30.2 +/- 0.3 (range 19.2-54.4). Julie Sprafka was at times heavy and obese based on CDC definition. She was on the younger side for a total knee patient, but somewhat inactive. Her weight was in about the 85% for a North American female in 2016.

Table: Mean and 95% weights of US Citizens ages 50-59 between 1988 and 2014.

	Mean and 95% Weights in the USA, Age Group 50-29[187]			
	50% Male	95% Male	50% Female	95% Female
1988-1994	184.7	251.3	157.2	239.9
1999-2002	190.6	264.1	161.9	249.4
2003-2006	195.5	274.3	162.5	259.7
2007-2010	195.4	279	161.4	255.3
2011-2014	195.9	279.4	167.4	271.3

For 50 to 59 year olds, between 1988 and 2014 the 95% male weight in the US has increased from 251.3 lb to 279.4 lb and the 95% female weight from about 239.9 lb to 271.3 lb. Between 5% and 10% of the Orthopaedic total hip and knee patients are morbidly obese, and their weights are likely greater than the 95% weights identified above. I have inspected several hip stem implants and a few knee components retrieved from patients weighing between 240 and 380 lb.

In 2015 ASTM F3141-15 issued a “Standard Guide for Total Knee Replacement Loading Profiles” (currently F3141-17). This guide document is based on the work and publications of Bergmann

and his associates at Research associate at the Julius Wolff Institute for Biomechanics and Musculosketetal Regeneration at Charite University in Berlin, Germany who have made their research work available to the public. Refer to https://orthoload.com/. Dr David Lunn and Professor Anthony Redmond at the Leets Teaching Hospitals NHS Trust & NIHR Leed Biomedical research Centre have validated a mathematical model of the forces in the knee during a stumble (AP shear of > 500 N or 1124 lb) and have generated a laboratory test for knee implant which evaluates the tibial implant-bone stability under stumble conditions. They have found that cemented PS style implants in a dry environment may experience posterior lift-off due to breakdown at the bone-cement interface.

Taylor et al summarized the complex in vivo loading of the tibial tray fixation-bone interface:

> "The tibial tray experiences complex loading during activities of daily living (ADL) comprising a combination of axial, anterior–posterior (AP), and medial–lateral loads, as well as flexion–extension, varus–valgus, and internal–external (IE) moments. Until recently, our knowledge of the magnitude and temporal variation of these loads has been limited, but recent data from telemetric implants[22,23] provides detailed information invaluable for pre-clinical testing. Various experimental and computational studies investigated the primary stability of cementless tibial trays.[24–30] The majority used simplified loading conditions incorporating only the axial load[24,26,28–30] either distributed to the medial and lateral condyle or applied as a unicondylar load case. Typically, these studies used a force equivalent to the peak load that occurs during the stance phase of gait. Some experimental studies explored other loading modes. Walker et al.[31] applied AP shear and IE moments to assess micromotion of different cementless designs. Sala et al.[32] applied a combination of axial load and IE moments. Interestingly, they reported that high micromotions were associated with low axial loads and moderate IE moments. A comprehensive loading regime was applied by Chong et al.[25] in a combined experimental and numerical study. They applied a range of loads simulating gait and stair climbing using combinations of axial load (shared between condyles) and AP and ML forces. When simulating gait, the highest micromotions were predicted at toe off, when the axial load was low and the AP forces were high. Taylor et al.[33] used a combined rigid body modeling and finite element (FE) approach to assess primary stability of various tray designs. The rigid body model was used to calculate the condylar reaction forces and contact positions during level gait, and these were then applied to an FE model of the implanted proximal tibia. They reported that peak micromotions occurred just prior to toe-off. Although the axial loads were relatively low, the posterior position of the femoral condyles resulted in anterior lift off of the tibial tray."

> "Peak micromotions occurs as a result of the maximum axial force, the peak micromotions (also) occurred as a result of low axial forces combined with a moderate varus moment."

The order of magnitude of the motion documented is similar to that that documented by others during in vitro cadaver studies of proximally cemented tibial trays.[188,189] In Taylor's work stair ascent and descent generated the highest micromotions, closely followed by level gait. Mündermann et al [190] measured a 1.1x to 8x differential between medial and lateral compartment loads following total knee arthroplasty. The peak knee joint load and the flexion angle where the peak load occurs differ substantially among different activities of daily living. The primary stability of an implant depends on the micromotion of the bone–implant interface, which depends on the kinematics and kinetics of the replaced joint. Even though Taylor et al

was discussing cementless fixation of a different implant system (DePuy LCS) , their work highlights the need for application of more relevant loading conditions for assessing the primary stability of tibial trays.

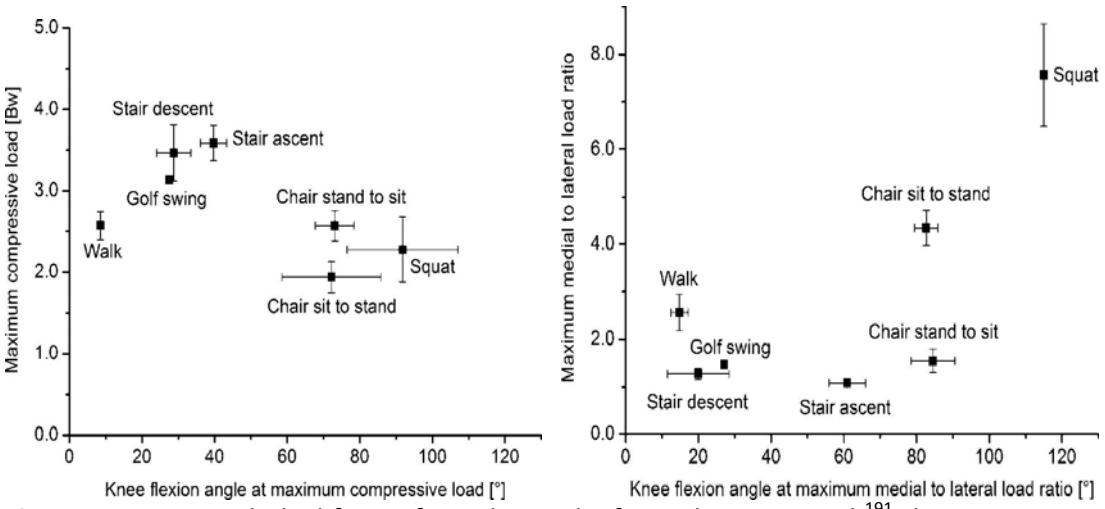

Figure 43: Measured tibial forces from the work of Mündermann et al [191] showing variations in load magnitude and media to lateral load shifts for different common activities

Activities that require increased loaded knee flexion (i.e. Stair climbing, chair rising and sitting, deep knee bends etc.) impose higher forces at the tibial interfaces. Axial loads due to muscle forces and weight-bearing affect motion and thus cyclic forces in vivo.

Thus limiting motion between the tray baseplate and bone is essential in a cemented application and is typically controlled by (1) the adhesion or mechanical lock between the hardened PMMA bone cement and the implant; and (2) the tray baseplate and the integrity of the cement-bone interface. Anterior lift-off during knee flexion and posterior lift-off during knee extension induces a tensile load in cement, and cement is weaker in tension and shear vs. compression. A debonded base tray-cement interface provides another source for wear debris generation.

APPENDIX C – SELECTED TEAM DISCUSSION - TIBIAL BASEPLATE FINISH

September 12, 2007 team design meeting [DEPATT 127929/930]

- Ranawat indicated he thought the surface roughness on a prototype sample was too rough in regions, which were not the undersurface of the base. The rough surface, like MBT finish, was OK there, but not on the keel or stem.
- Tom Thornhill (surgeon) indicated that Scorpios , with a similar, but larger, swept keel and has had clinical problems with loosening at the cement-implant interface. He suggested that undercuts on PBB trays might secure the cement -implant interface. [DEPATT 127929]
- Doug Dennis (surgeon) asked if the stem and keel could be masked to have a smoother surface finish , but keep the rougher surface finish on the tray undersurface. Auger (DePuy) indicated that this could be done, but would cost more.

In a December 12, 2007 team design meeting [DEPATT 00128032/34]

- Auger (DePuy) noted that they were continuing to investigate undersurface features. [DEPATT 00128033]
- At the same time there was discussion of doing toggle and pistoning tests (*of insert / lock mechanism*) Compare to Bannister & Sigma.
- Goldstein (surgeon) noted that he had a concern with AP thrust and impaction during insert insertion causing disruption of cement.

In the same December 12, 2007 team design meeting [DEPATT 00128038/39]

- Dennis indicated that there needed to be a uniform method of cementation and something to control cement penetration as this could greatly effect pullout.
- Barret noted that his team had been looking at smart cement pockets to improve cement fixation, and wanted to know if it was too late to add to the implant.
- Thornhill: reminded the team that Merrill Ritter MD has discussed Scorpio metal cement interface failures.
- Ranawat contributed that clinically the MBT cement tray junction is typically a lot stronger than the cement-bone junction. He intimated that he favored a slight reduction of the tray-cement interface strength.

In a March 14, 2008 team meeting [DEPATT 000127866/868] [DEPATT_00128173/175] [DEPATT_00131228/230]:

- Deffenbaugh (DePuy) presented pull off test results for trays with different surface finishes. Based on the testing they eliminated a zirblast finish. The 20 grit as utilized on the clinically successful MTB performed better that other blast finishes in this simplistic test. No discussion of the cement mixing or application parameters.[R] [Data located at : DEPATT_00132112]

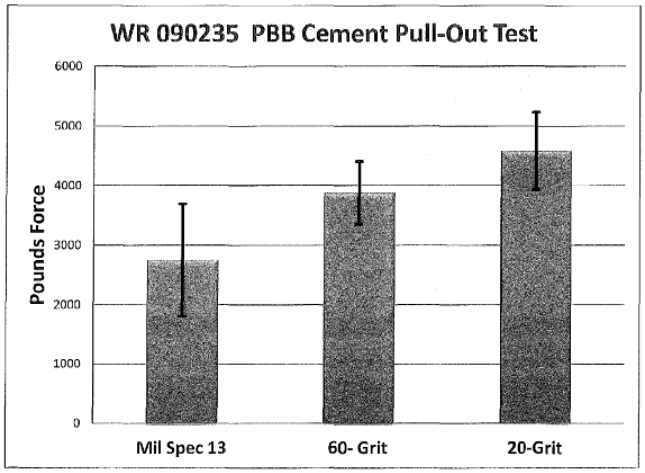

Figure 44: The pull-out strength of the Mil Spec 13 blast was significantly less than that of 60 Grit ($p<0.01$) and 20 Grit ($p<0.001$). There was no significant difference between the 60 Grit and 20 Grit ($P=0.096$) even though the average value of 20 Grit was greater than that of 60 Grit.[DEPATT_00132112/113]

- Tom Bermasek (surgeon) stated that Ra is not the best measure for cement- implant adhesion.
- John Wright (surgeon) notes that Ra is not a good predictor of cement fixation.

[R] The cementation stage or application time, or mixing method (sticky vs dough, vacuumed mixer vs hand) was not described in the test method. The stage in which the cement is applied changes the adhesion to the implant surface.

- Deffenbaugh(DePuy) also noted that Ra is often misunderstood and was probably not the best measure.
- AMK helps us establish a lower boundary.
- Callaghan (surgeon) notes that the PBB knee will have higher performance and larger demographics.
- Wayne Goldstein(surgeon): In the PBB implant, we are expecting more performance and higher flexion, so we may want more fixation than the AMK.
- Dan Auger (DePuy R&D, Knee Fellow) believed that the team would end up between glass bead blast and mixed grit blast compromise.
- Tom Fehring (surgeon) noted that cement -implant interface failure does not occur vertically (as done in the in the pull off test DePuy was using to differentiate interface performance) . He suggested splitting the load and looking at offset load to see how it rocks out.
- On this point, Auger noted that historically DePuy has done this, and he believes shear is a bigger problem than tension. He stated that DePuy would look at pullout characteristics and other (not delineated) physical parameter tests. He did not believe Ra comparisons, alone, would assure fixation.
- Tom Bernasek (surgeon) favored rougher surface finish as on the MBT. He has no have problems with that rough fixation clinically. Others in team had apparently voiced a concern that the fixation would be too strong and thus make it more difficult to remove the tray in a revision.
- Ranawat reminded all that high roughness on keel is a problem for removal.
- Barrett (surgeon) recommended a pull-out and eccentric loading test to support surface finish change.
- Dan Berry (surgeon) liked the finish on the historical Ti alloy trays, but there was team concern that the new tray geometry on the PBB (verse the older devices like Sigma) combined with that surface finish would not be sufficient.
- Dave Dalury (surgeon) notes that DePuy would have a hard time mimicking conditions to find convincing data in the timeframe needed to make a decision. He suggested that DePuy find a surface finish between all-poly AMK (worst performing) and the MBT (*which had the best cement adhesion in pull out testing and had a long history of being clinically successful*).
- Dan Berry warned the team to be careful from deviating from what is known to work. He further stated that the team should not choose compromise and end up with something worse as has happed in the past with with cemented hip fixation. Compromise does not work in hips, but polished and grit blasted both work (for different reasons, different hip styles).
- David Barrett (surgeon) recommended a pull-out and eccentric loading test to support surface finish change. He did not feel that the laboratory testing proposed was sophisticated enough to rely on to assure adequate fixation in vivo. He was concerned about inadequate interface stability in the new design and recommended using a surface finish found on a historical product with long clinical history.
- Dowd warned that any (surface finish) change one-way or the other has a great impact on bonding.
- Auger bet that there would be further investigation of fixation in the future.
- Deffenbaugh suggested that they would probably end up with a #3 or #4 glass bead blast finish.
- Auger noted that DePuy would probably end up between glass bead blast and grit finish.

- Goldstein noted that this knee is higher performance and will need grater interface fixation strength. In the PBB implant, we are expecting more performance and higher flexion, so we may want more fixation than the AMK.
- Callaghan (surgeon) also notes that the PBB knee will have higher performance and larger demographics.
- Auger (DePuy) noted that Geometry has been frozen on the tray design, so the only opportunity to adjust fixation (cement-implant interface bond strength) at this juncture was with surface finish.

June 2008 team design meeting [DEPATT00128196, 202/203]

- Auger: Sigma is glass and MBT is 20 grit. [DEPATT00128196]
- Berry: We want to make sure the interface is strong enough so it is not failing. [DEPATT00128196]
- Callaghan: I saw a failure between the the cement and the tray in revision. [DEPATT00128196]
- Auger: Revision is generally release at bone-cement interface. We got complaints on glass bread blast due to aesthetics. We get complaints on 20 grit being too rough. We propose going with 60 grit. [DEPATT00128196]
- Berry: Once we make the tray, we would like to cement them onto bones and then knock them off. [DEPATT00128196]
- Concern: Femur loosening in deep flexion use as in Zimmer Nexgen Flex. [DEPATT 00128202/203]
- Ranawat: The adhesiveness of the cement to the implant is more critical than whether the femoral implant lugs have undercuts or not. [DEPATT 00128202/203]
- Heldreth: An undercut will add time and cost to the implants. If we were to put a proper grit blast on the entire internal femur geometry, including the lug, I believe that the holding strength will be close to the undercut. [DEPATT 00128203]
- Auger: On the CR we went with lugs with straight ribs. We are trying to assess what to do on the PS. Vote went straight ribs. [DEPATT 00128203]

July 2008 team design meeting [DEPATT 00128207]

- Deffenbaugh presented PPT material and case for 60-grit alumina oxide on tibial base and femoral box. This finish has not been used on prior implants.
- Auger : 20 grit has had complaints due to firm fixation and proposed use of the 60-grit process.
- Goldstein stated it could be hard to extract an RP (with 20 grit surface finish), but that means fixation is really good. Easy cut might mean easy to fail.
- Callaghan proposed testing cementation of part with the new 60-grit finish in a cadaver lab.
- Goldstein reiterated that loosening is not simple tension, not simplistic axial pull as per test proposed.(Rocking/tilting shear and tension)
- The team voted to move forward with 60-grit blast following Deffenbaugh presentation this discussion.[S]

[S] I noted that there was no consideration at this point to application of the 20 grit to the undersurface and the 60 grit to the keel and stem as suggested in prior meetings.

APPENDIX D BACKGROUND: TIBIAL CEMENT MANTLE THICKNESS & BONE-CEMENT INTERFACE TENSILE STRENGTH

Appropriate tibial bone preparation and pressurization will improve bone-implant fixation. Ms Sprafka's bone-cement interface was robust.

It has been shown that the penetration depth necessary for non-osteoporotic bone can be expected to be slightly lower than the 1.0 mm estimated for the high-density group, because non-osteoporotic bone has a lower porosity. Nagel et al [192] has shown that to maximize fixation strength, a mean cement penetration depth of at least 1.1 mm should be achieved during tibial tray cementing. The mean penetration of 1.1 mm relates to a maximum depth (not including pin holes) of around 2 mm. A maximum depth may be an easier parameter for the surgeon to aim for than the mean penetration.

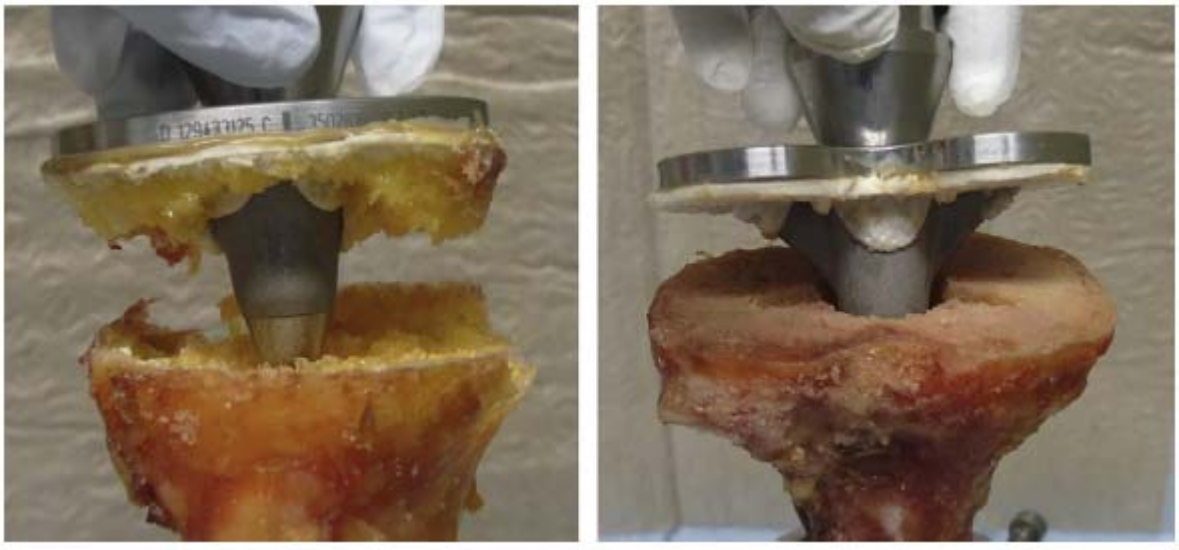

Figure 45: Specimens failing in the BULK bone (left, n = 13) or at the cement-bone INTERFACE (right, n = 10) were analyzed by Nagel et al.[193]

Nagel et al[194] (2017) complete pull out testing of cemented tibial baseplates. BMD below the tibial plateau of non-osteoporotic patients has been determined to be 122 mg/cm^3 and greater. The BMD of the specimens tested were in the range of severe to mild osteoporosis. The mean BMD for all specimens was 79 ± 34 mg/cm^3. The low-density specimens (n = 11) had a mean BMD of 53 ± 18 mg/cm^3 and the high-density specimens (n=12) had a mean of 104 ± 25 mg/cm^3. Specimens were separated into a group failing in pull-out at the cement-bone interface (INTERFACE) and one failing in the bulk bone (BULK). The authors identified thresholds between BULK and INTERFACE failure in cemented tibial implants. For mean cement penetration the threshold value is 1.1 mm and the maximum penetration threshold is f 5.6 mm. The maximum penetration is likely to be a less robust criterion for achieving bulk bone failure than the mean penetration because it represents a single feature, rather than the integrated morphology of the cement mantle, and a single local deep cement penetration would seem unlikely to deliver much overall strength, regardless of its maximum depth.

Nagel et al [195]documented: The maximum pull-out strength of a tibial tray component does not increase further with cement penetration above a certain threshold and that it can be predicted from cement mantle morphology parameters and BMD. If the cement-implant interface is strong enough and the morphology parameters of the cement mantle penetrating the bone are greater than the thresholds determined, the pull-out strength is limited by the strength of the bulk bone, which itself is dependent on the BMD.

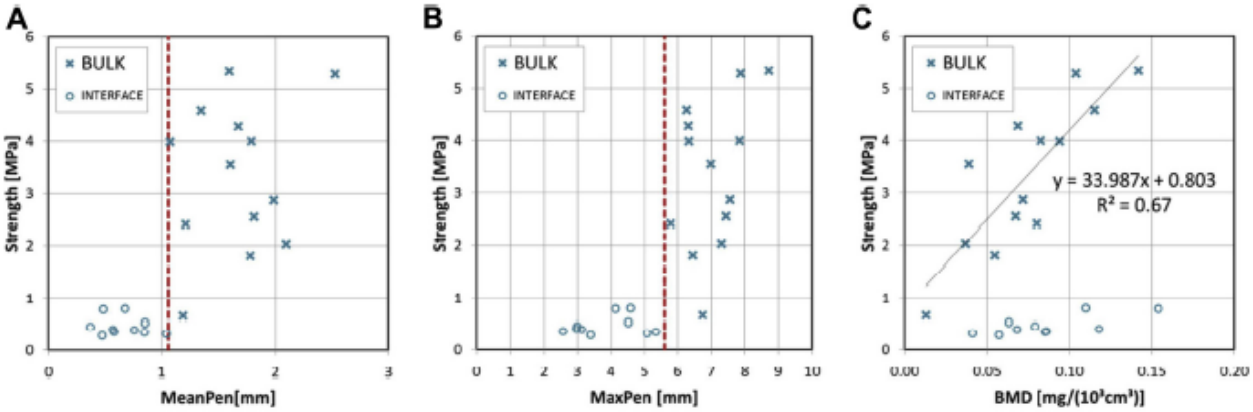

Figure 46: Strength of INTERFACE and BULK failure specimens related to MeanPen (mean penetration), MaxPen (maximum penetration), and BMD.

Nagel et al also noted:

i. Pull-out strength has often been used as a measure of the stability of the cement-bone interface, although it is a rather non-physiological loading mode. Pull-out testing assesses the general strength of the interface, which should also apply to physiological loading. Whether the pull-out strength represents the extent of cyclic relative motion between bone and cement under cyclic loading remains to be demonstrated. In deep knee bending, tensile pull-out forces may occur at the tray-tibia interface due to unicondylar lift-off of the femur, which has been reported in 75% of patients. In this scenario, the compressive condylar load acting on only one side of the tibial plateau generates a moment around the anteroposterior axis, potentially leading to tensile forces on the other side of the plateau.

ii. The topography of the cement-bone interface of the cement mantle does not change greatly with penetration depth, which can be attributed to the basic trabecular structure.

iii. The volume of cement penetrating into the bone is less predictive of failure mode than the mean penetration, indicating the importance of a good distribution of the cement on the plateau.

iv. The influence of the cement mantle morphology in the region of the plateau on the pull-out strength dominates over that of the stem cement volume.

v. In revision surgery, the cement must be completely removed along with the interdigitated trabecular bone. Thus, the loss of bone stock is directly related to the volume of cement used in the primary implantation, which should be limited. This work provides clear evidence that there is no strength-related benefit in over penetration and that this is independent of bone quality (it was noted that sclerotic bone requires special cementation techniques).

Cement-trabecular bone interface

In cemented knee arthroplasty, the bone cement is intended to interlock between trabecular bone and cement, providing initial fixation of the implant to bone. Trabeculae that initially interlock with PMMA cement in knee replacements are not in direct apposition; small gaps exist over much of the interface between cement and bone. [196] When loaded, there is a small amount of micromotion between the trabeculae and cement, with a greater degree of micromotion near the cement border compared to deep within the cement layer. With invivo use, local trabecular resorption causes gaps between the trabeculae and cement surface to become much larger. The larger gaps allow for more micromotion near the cement border. For some cases, in which there is extensive trabecular resorption, the trabecular bone remaining deep in the cement layer can have small gaps and negligible micromotion.[197]

It is also important to note that extensive trabecular resorption does not consistently occur in all in vivo cases, and that generally this response occurs over time. The postmortem retrievals studied by Miller et al[198] exhibited a wide range of interlock morphology and micromechanics, and this variation may depend on donor sex, age, and time in service. The least resorption and micromotion occurred in a relatively young 61-year-old male with 5 years of in vivo service, suggesting that robust interlock at the interface can be maintained, at least in the short term. In contrast, the two donors with extensive resorption and the most micromotion were female, 69 and 75-years-old, with 11 and 16 years of in vivo service. Local trabeculae-cement morphology affects interlock micromotion and bone strain. For postmortem retrievals where there was less initial interlock and more time in service, there was more micromotion between the remaining interlocked trabeculae and cement. It should be noted that there was no evidence of lytic lesions in the bone surrounding any of the postmortem retrievals tested in the studies by Miller et al.[199] The post mortem specimens with substantial remaining interlock exhibit very small micromotion (< 1 μm), at the cement-bone interface while those with substantial trabecular resorption have greater micromotion (> 10 μm) near the cement border

The mechanism or mechanisms that cause resorption of trabecular bone that initially is interlocked with PMMA cement is not clear, and may be multifold. Srinivasan et al[200] noted that in cemented TKA, loosening occurs at the cement-trabecular interface probably due to a stress-shielding effect of the stiffer implant material in comparison with bone. Strain adaptive remodeling is a plausible mechanism responsible for loss of interdigitated bone. It appears that trabecular resorption may first occur closer to the cement border, compared to deep in the cement layer. Strain shielding of trabecular bone that interlocked with the cement could initiate a local resorption process. Pumping of fluid along the thin gaps of the trabeculae-cement interface could cause high local shear stresses and pressure and result in fluid induced osteolysis, but evidence suggests that fluid flow and high fluid pressure induced by cement-bone interface micromotion may not be the main cause for the bone resorption seen in the retrievals. Analyses of tibial retrievals showed significant resorption in bone surrounded by cement, while at the cement border the bone remodeled to form pedestals to support the cement mantle. When a thicker cement mantle is present, the most proximal bone would get completely encapsulated in cement. It is possible that due to a lack of vascularity, the entrapped bone cannot be resorbed.

When present, ions and other wear debris transported from loose modular connections or from the articulating surface can also migrate along this fluid interface and can initiate focal bone loss or osteolysis.[201, 202]

From a clinical perspective, attaining more initial interlock appears to result in cement-bone interfaces that are better fixed with less micromotion. This is desirable from the perspective of minimize pumping of fluid or debris along the interface and maintaining interface strength.[203] In

Zimmerman et al[204] noted:

> "Clinically, the risk of aseptic loosening is known to be higher for younger TKR patients and revision risk increases for implants with longer time in service (Julin et al., 2010). Younger patients are likely to be more active and may generate larger loads on their knee replacement, while implants with long time in service may be associated with a reduction in the amount of bone supporting the knee replacement due to stress shielding (Huiskes et al., 1987; Levitz et al., 1995; Li and Nilsson, 2000) and loss of mechanical interlock between the implant and bone (Goodheart et al., 2014; Miller et al., 2014)."

Based on Dr. Breien's description, Julie Sprafka did not have significant resorption of trabecular bone or loosening of her tibial implant at the bone-cement interface.

Post & Keel Length

In 1983, Crowninshield et al showed that tibial components with metal backing and 35 mm central posts reduce the proximal trabecular bone compressive loading (compared to all-polyethylene tibial components). (The post length in Ms Sprafka's implant was almost 35 mm (at ~33 mm) below the flat cement fixation surface.) Stress transfer from a central fixation post is related to the post length, post rigidity, and surrounding rigidity. A 35 mm central post has limited effect on proximal tibial load transfer because surrounding trabecular bone is of relatively low modulus of elasticity(stiffness), however an increase in stress transfer (and bone density) occurs at the trabecular bone surrounding the post's distal tip. The addition of longer rigid metal post has a larger effect on proximal tibial load transfer. Longer metal central fixation posts can substantially unload the proximal tibia if adequate distal cement is provided. This type of long central post prosthesis may be desirable in cases of revision surgery where substantial trabecular bone loss has occurred and proximal tibial stress shielding is desired[205] or in high demand patient cases where there is a high risk of proximal tibial trabecular bone overload. Walker et al.[206,207] concluded the same empirically in 1980 and 1981. Under low loads of 1500 N (337 lb.) cemented short stems (~ 38 mm) are sufficiently stable.[208] However, a high demand patient will apply loads ~ 3 to 5x higher. Stability characteristics of cemented tibial trays under high-demand patient load conditions are warranted.

The strength of the proximal tibial bone varies by location in the tibia, pre-operative diagnosis and the patient's bone density.

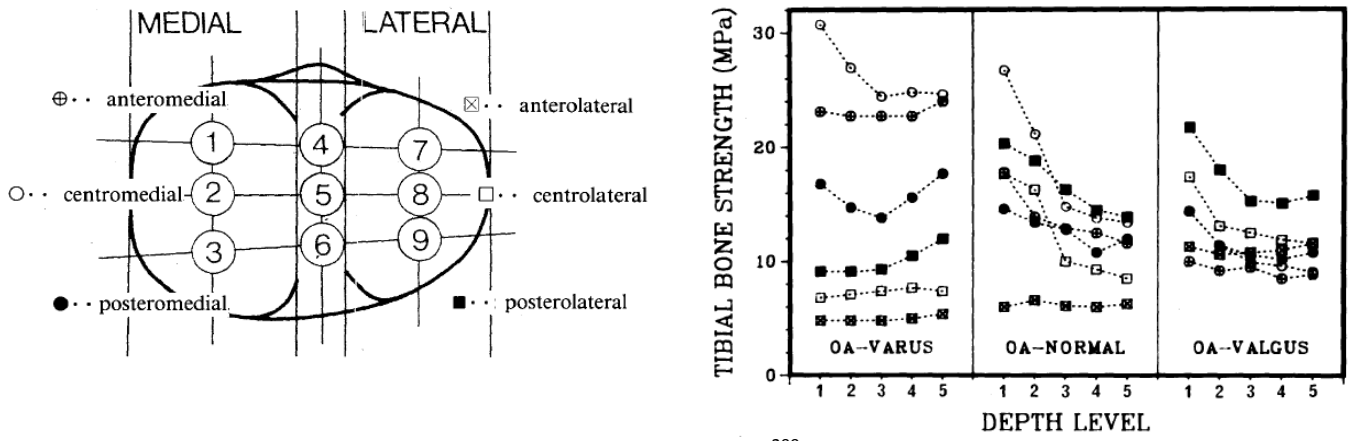

Figure 47: Mean tibial trabecular bone quality map from Hvid[209] (1988) Round = medial; Square = lateral.

Given cortical bone coverage, and assuming a typical tibial tray and a 33 mm stem implant there is "generally" sufficient implant surface area and trabecular bone strength to support the implant in today's average male size (~210 lb. for males) with average osteoarthritis (OA) bone quality, particularly if they are not high demand users. However, for high demand patients (heavier or more active) or those with weaker bone, the bone-cement interface or the tray-cement may be repetitively overloaded. There is a significant decrease in motion of the tibial tray with increasing press-fit stem length (75-150 mm) and increasing stem diameter (10-14 mm). Cemented tibial stems showed significantly less tray motion than uncemented stems. Short cemented stems produced tray stability equivalent to long press-fit stems. Although there was a trend for increased proximal tibial stress shielding with the use of cement and longer, wider stems, the trend is not statistically significant. Modular, press-fit stems can achieve tray stability similar to a smaller cemented stem and can avoid the potential problems with cement.[210]

Micromotion of Cemented Tibial Trays

Teetering occurs regardless of loosening

It is well documented that a teetering effect occurs at the distal tip of a central stem in tibial implants occurs due to physiologic loading applied in normal activities of daily living.[211,212,213,214] In appropriately cemented stemmed tibial implants like the Attune tibial baseplate implanted into Julie Sprafka, the motion induced by physiologic loading is at a level consistent with a durable and stable fixation, which is below 150 μm, the level known to induce an organized fibrous interface adjacent to total joint implants. Ms Dibala' s tibial baseplate implant was oriented, sized, placed and cemented in a manner known to achieve a stable and durable fixation.[215,216, 217,**218**] The cement mantle was relatively even and was spread over the entire plateau and around the stem and it appeared on x-ray to be thick enough to provide stability, but not too thick to cause early proximal bone loss due to stress shielding.[219,220,221,222]

It should be noted that fibrous tissue develops preferentially when micromotion exceeds about 150μm at an implant interface.[223] In vitro testing of cemented stemmed tibial implants have documented that central loading produces a distal translation with minor rotations, posterior loading results in a posterior tilt with perhaps some distal translation, and medial loading causes

a medial tilt. In general, the differences in the motion patterns under the three loading conditions are common to each stem and cement configuration. [224] Stern et al[225] also documented shown that cemented short stem tibial implant micromotion ranged from 31 to 49 μm due to a 1500 N (337 lb) compressive force. For a 254 lb person a maximal net force in the range of about 762 lb, and a peak unilateral (medial biased) force of about 609 lb may occur during walking following TKA.[226] (607 lb/337 lb = 1.8; 762/337=2.26) Assuming a linearly proportional increase in micromotion with loading the micromotion near the cemented implant would be maximally about 111μm, or less than 150μm. This is consistent with the finding measured by others. For example, Zimmerman et al[227] similarly assessed the fixation strength of 17 tibial components from post mortem retrievals that were functioning for the patient at the time of death an one time zero implant. (18 en bloc tibial components , 0 to 22 years in service BMI range of 22.7 to 36.5, maximum weight 220 lb, BMD range from 0.07 to 1.16 gr/cm^3).

In Zimmerman's study, all of the retrieved tibial implants were metal backed and attached using bone cement. Forces proportional to body weight of the individuals were applied to replicate activities recorded in living TKA patients. Bone strain was compared to the known range of yield strain of tibial trabecular bone (−7300±600με) (Morgan and Keaveny, 2001). Similarly, a micromotion limit of 150μm was used as an indicator of an implant-bone interface that would be unable to sustain stable fixation (Jasty et al., 1997). A range of ±50μm was used to assess the sensitivity of the micromotion limit. Failure was considered to occur when micromotion exceeded 150 μm or compressive bone strain exceeded 7300 με.

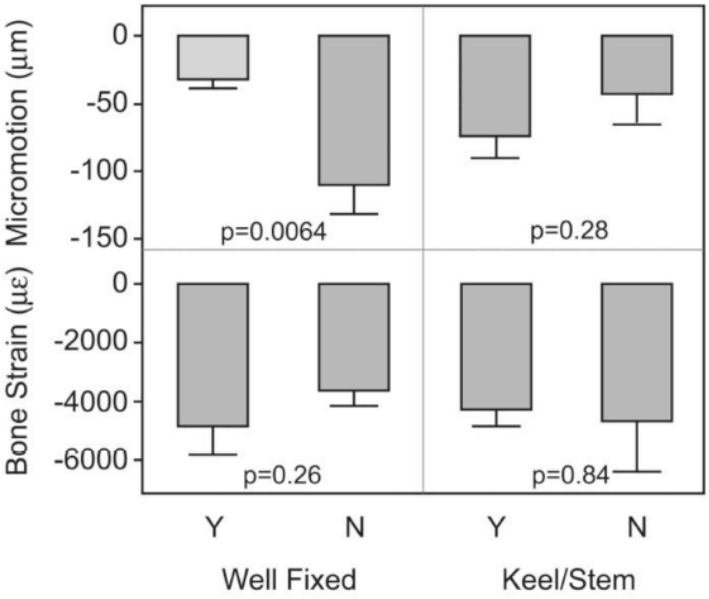

Figure 48: Data from the work of Zimmerman et al. [228] Total micromotion and proximal bone strain at 6 BW loading stratified by radiographic fixation status and presence of a keel or stem. P values from two sample t-tests are shown.

None of the sample population had supporting bone damage at 4 BW, but further increases in applied load resulted in a larger fraction of the population with bone damage. All retrieved specimens had sufficient bone strength to support most activities of daily living, but ~40% would be at risk under larger physiologic loads that may occur secondary to a higher impacts such as jogging or a stumble. For the donor bones that were possibly loose based on tray/bone radiolucencies, there was much greater micromotion (**Figure 48**, data shown for 6BW) compared to implants that appeared to be well fixed. There were two donor knees with excessive total micromotion (>150μm) even at low load magnitudes (2BW). However, loads of 8BW or greater were needed to cause any of the other knees in the sample population to exceed the 150μm micromotion limit.

With 6 BW applied, total micromotion ranged from 14 to 215μm with a median of 54μm. The location of the largest micromotion did not occur in a consistent region with 38% occurring in

the medial region, 33% in the posterolateral region, and 28% in the posteromedial region. The tray-bone micromotion was greater for donors with lower age at implantation while the proximal bone strain was greater for donors with longer time in service. Distal bone strain (was greater for donors with more time in service and lower peri-implant BMD. The authors noted that high mechanical overload of a single or repetitive nature may be an initiating factor in aseptic loosening of total joint arthroplasties and should be avoided in order to prolong the life of the implant.

Julie Sprafka weighs about 215-220 lb, but she was at most moderately active and used a cane to aid in ambulation. The walking forces on her knee are somewhat higher than the North American Female, but were typical for TKA patient. Considering this, the bone-cement interface micromotion due to loading would have been below 150 μm. RE: Without documentation of extremely poor bone quality or extremely low BMD, there is no support reason to suspect instability at Julie Sprafka's tibial bone-cement interface.

APPENDIX E DEPUY'S NON-COMPLIANCE WITH FEDERAL CODE CFR 803 MDR REPORTING

I have seen some evidence of DePuy's non-compliance with Federal Code CFR 803 specifically concerning the Pinnacle metal-on-metal (MoM) total hip arthroplasty (THA). During a May 10, 2011 through June 7, 2011 FDA inspection of a DePuy facility located in Warsaw, IN, the FDA auditor uncovered problems. A Form 483 with four observations were issued to DePuy concerning deficiencies in risk assessment and complaint handling involving the Pinnacle Ultamet liners (Metal-on-metal hip products). Observations concerning deficiencies identified DePuy' s complaint handling and Corrective and Preventative Action(CAPA) processes, statistical analysis errors, as well as instances of DePuy's failure to report serious injuries to the FDA as required by 21CFR803 (Sec. 803.50, 803 .12(a) and 803.52). The FDA Observations 1, 2 and 3, directly related to complaint handling:

OBSERVATION 1

"Results of the design risk analysis were not adequately documented."

"Specifically, your firm has not adequately defined and established the process in which design failure modes and effects analysis (DFMEAs) will be developed and documented. For example, your firm has not documented the rational used to determine the scoring results of the DFMEAs for the Pinnacle Ultamet metal inserts, Pinnacle M-Spec metal femoral heads, and Pinnacle aSphere femoral heads. The objective evidence used to determine the scores given to the severity and occurrence of each possible failure is not documented. Additionally, your firm has not established how these scores will be reviewed and updated based upon continued postmarket surveillance data (e.g., complaints) your firm receives."

OBSERVATION 2

"Complaints involving the possible failure of a device to meet any of its specifications were not investigated where necessary. Specifically, your firm's procedure WI-2288, "Product Complaint Investigation" states that complaints are either nonverifiable, unconfirmed, or confirmed. It further states that a complaint can be confirmed based upon supporting data

to include "DHR Review" and "specific, verifiable information provided from the patient/surgical record, e.g. X-rays, surgical notes". Your firm was notified of a complaint (WPC 3874-2009) where metal debris and necrotic tissue were found within the patient of an internal IDE study in which X-rays were taken and available within your firm's clinical department in charge of the IDE study. However, your firm's complaint database states that no X-rays were available and were not reviewed in the investigation conducted by your firm."

"Similarly, your firm received complaint WPC 2745-2011 which referenced "pseudotumor, osteolysis, and soft tissue reaction" which resulted in a revision; however, X-rays were not reviewed and your internal complaint database stated X-rays were available. It was reported that the product failed to meet specifications and that the product contributed to the revision."

OBSERVATION 3

"Procedures for receiving, reviewing, and evaluating complaints by a- formally designated unit have not been adequately established."

"Specifically, your firm has not established how all sources of where complaints can be generated will be reviewed and evaluated within the complaint system. Procedure SCP-1403, "Complaint Handling Procedure (rev. N, released 8/18/2006) states that a complaint is "any written, electronic, or oral communication that alleges deficiencies related to the identify, quality, reliability, safety, effectiveness or performance of a device after it is released for distribution" and that any of your firm's employees are to inform Customer Quality as soon as possible after becoming aware of a confirmed or suspected product complaint (recommended within 48 hours)."

"However, two of eight complaints reviewed from your firm's internal clinical data sources (e.g., DOTS and IDE clinical trial groups) were not entered into your firm's complaint system in a timely manner. Your firm was notified of complaint WPC 6131-2011 on 3/23/2009, which was entered into your complaint database on 5/26/2011, (approximately 794 days after notification). Similarly, your firm was notified of complaint WPC 6132-2011 on 3/30/2009 which was entered into your complaint database on 5/27/2011 (approximately 788 days after notification)."

OBSERVATION 4

"Procedures for Corrective and Preventative Action have not been adequately established." …

OBSERVATION 5

"Procedures have not been adequately established to control product that does not conform to specifications." …

In the case of the two complaints that were cited in FDA audit Observation 3, it was noted that there was not process in place at DePuy to assure revisions were reported as adverse events (AE) prior to mid-2011. Thus, DePuy complaint statistics pre-2011 was biased low, even when revisions were reported to the company.

References

[1] Murphy JD, Braunlich PR, Judson WR, Harker JN, Baumann PA: **Early Aseptic Failure of the Tibial Component- Cement Interface in ATTUNE® Total Knee Arthroplasty: A Report of Three Cases**
Cureus.2021 Dec 21;13(12):e20582.

[2] Bonutti PM, Khlopas A, Chughtai M, Cole C, Gwam CU, Harwin SF, Whited B, Omiyi DE, Drumm JE.: **Unusually High Rate of Early Failure of Tibial Component in ATTUNE Total Knee Arthroplasty System at Implant-Cement Interface**. *J Knee Surg.* 2017 Jun;30(5):435-439.

[3] Hazelwood KJ, O'Rourke M, Stamos VP, McMillan RD, Beigler D Robb WJ: **Case series report: early cementimplant interface fixation failure in total knee replacement.** *Knee* 2015;22:424–428.

[4] Bonutti PM, Khlopas A, Chughtai M, Cole C, Gwam CU, Harwin SF, Whited B, Omiyi DE, Drumm JE.: **Unusually High Rate of Early Failure of Tibial Component in ATTUNE Total Knee Arthroplasty System at Implant-Cement Interface**. *J Knee Surg.* 2017 Jun;30(5):435-439.

[5] Rebgetz P, Kovacs A, Bochat K, Hayes A, Clark G, Blakeney W, Pabbruwe M: L**oosening of tibia baseplates after total knee arthroplasty: Evaluation of pull-out strength of tibia baseplate-cement Interface.** *Clin Biomech (Bristol, Avon).* 2021 Dec;90:105497.

[6] Murphy JD, Braunlich PR, Judson WR, Harker JN, Baumann PA: **Early Aseptic Failure of the Tibial Component- Cement Interface in ATTUNE® Total Knee Arthroplasty: A Report of Three Cases** *Cureus*.2021 Dec 21;13(12):e20582.

[7] Cerquiglini A, Henckel J, Hothi H, Allen P, Lewis J, Eskelinen A, Skinner J, Hirschmann MT, Hart AJ: **Analysis of the Attune tibial Tray backside: a comparative retrieval study**. *Bone Joint Res*. 2019;8(3):136–145.

[8] Kelly BC, Owen JR, Shah SC, Johnson AJ, Golladayt GJ, Kates SL: **A Biomechanical Comparison of the Effect of Baseplate Design and Bone Marrow Fat Infiltration on Tibial Baseplate Pullout Strength** .*J Arthroplasty*. 2021 Jan;36(1):356-361.

[9] Kaptein BL, den Hollander P, Thomassen B, Fiocco M, Nelissen GHH: **A randomized controlled trial comparing tibial migration of the ATTUNE cemented cruciate-retaining knee prosthesis with the PFC-sigma design**. *Bone Joint J.* 2020 Sep;102-B(9):1158-1166.

[10] Rebgetz P, Kovacs A, Bochat K, Hayes A, Clark G, Blakeney W, Pabbruwe M: L**oosening of tibia baseplates after total knee arthroplasty: Evaluation of pull-out strength of tibia baseplate-cement Interface.** *Clin Biomech (Bristol, Avon).* 2021 Dec;90:105497.

[11] Jaeger S, Eissler M, Schwarze M, Schonhoff M, Kretzer JP, Bitshc RG: **Does tibial design modification improve implant stability for total knee arthroplasty? An experimental cadaver study.** *Bone Joint Res.* 2022 Apr;11(4):229-238.

[12] Staats K, Wannmacher T, Weihs V, Koller U, and Kubista B, Windhagert R: **Modern cemented total knee arthroplasty design shows a higher incidence of radiolucent lines compared to its predecessor**. *Knee Surg Sports Traumatol Arthrosc.* 2019;27(4):1148–1155.

[13] Sadauskas A, Engh C, Mehta M, Levine B: **Implant Interface Debonding After Total Knee Arthroplasty: A New Cause for Concern?** *Arthroplasty Today*. 2020 Dec 5;6(4):972-975.

[14] Giaretta S, Berti M, Micheloni GM, Ceccato A, Marangoni F, Momoli A: **Early experience with the ATTUNE Total Knee Replacement System.** *Acta Biomed* 2019 Oct 29;90(12-S):98-103.

[15] Kaptein BL, den Hollander P, Thomassen B, Fiocco M, Nelissen GHH: **A randomized controlled trial comparing tibial migration of the ATTUNE cemented cruciate-retaining knee prosthesis with the PFC-sigma design**. *Bone Joint J.* 2020 Sep;102-B(9):1158-1166.

[16] Staats K, Wannmacher T, Weihs V, Koller U, Kubista B, Windhagert R: **Modern cemented total knee arthroplasty design shows a higher incidence of radiolucent lines compared to its predecessor**. *Knee Surg Sports Traumatol Arthrosc.* 2019;27(4):1148–1155.

[17] Staats K, Wannmacher T, Weihs V, Koller U, Kubista B, Windhagert R: **Modern cemented total knee arthroplasty design shows a higher incidence of radiolucent lines compared to its predecessor**. *Knee Surg Sports Traumatol Arthrosc.* 2019;27(4):1148–1155.

[18] Staats K, Wannmacher T, Weihs V, Koller U, Kubista B, Windhagert R: **Modern cemented total knee arthroplasty design shows a higher incidence of radiolucent lines compared to its predecessor**. *Knee Surg Sports Traumatol Arthrosc.* 2019;27(4):1148–1155.

[19] Cerquiglini A, Henckel J, Hothi H, Allen P, Lewis J, Eskelinen A, Skinner J, Hirschmann MT, Hart AJ: **Analysis of the Attune tibial Tray backside: a comparative retrieval study**. *Bone Joint Res*. 2019;8(3):136–145.

[20] McCaskie, A W Deehan, D J Green, T P , Lock, K R Thompson, J R Harper, W M, Gregg P J: **Randomised, Prospective Study Comparing Cemented and Cementless Total Knee Replacement: Results of Press-Fit Condylar Total Knee Replacement at Five Year**s. *J Bone Joint Surg Br,* Nov 1998, 80 (6), 971-5.

[21] Cawley DT, Kelly N, McGarry JP, Shannon FJ.: **Cementing techniques for the tibial component in primary total knee replacement.** *Bone Joint J*. 2013 Mar;95-B(3):295-300.

[22] Saleh KJ, El Othmani MM, Tzeng TH, Mihalko WM, Chambers MC, Grupp TM.: **Acrylic bone cement in total joint arthroplasty: A review**. *J Orthop Res*. 2016 May;34(5):737-44.

[23] Vanlommel J Luyckx JP, Labey L, Innocenti B, De Corte R, Bellemans J.: **Cementing the tibial component in total knee arthroplasty: which technique is the best**? *J Arthroplasty*. 2011 Apr;26(3):492-6.

[24] Modern Cementing Technique Biomet Bone Cement R, Refobacin Bone Cement R, and Clearmix Vacuume Mixing System 1111.2-US-en-REV1217.

[25] **Attune Knee System Intuition Instrument Surgical Technique**, DSUSJRC03161437 Rev 4©DePuy Synthes 2017, 2018.

[26] DePuy Brochure. "**Attune knee system. Advancing Innovation with the Attune S+ Technology**." DSUS/JRC/0617/2207 08/17 ©DePuy Synthes 2017.

[27] Marx R, Qunaibi M, Wirtz DC, Niethard FU, Mumme T.: S**urface pretreatment for prolonged survival of cemented tibial prosthesis components: full- vs. surface-cementation technique**.*Biomed Eng Online.* 2005 Oct 31;4:61.

[28] Marx R, Qunaibi M, Wirtz DC, Niethard FU, Mumme T.: S**urface pretreatment for prolonged survival of cemented tibial prosthesis components: full- vs. surface-cementation technique**.*Biomed Eng Online.* 2005 Oct 31;4:61.

[29] Kuhn, KD .: **PMMA Cements**. Springer-Verlag, Berlin. 2014, p 183-229.

[30] Kuhn, KD .: **PMMA Cements**. Springer-Verlag, Berlin. 2014, p 194.

[31] Morita S, Yamamoto H, Furuya K, Ishihara K, Nakabayashi N.: E**nhanced strength in cemented stem fixation using adhesive acrylic cement as a metal coating material.** *J Biomed Mater Res.* 1997 Feb;34(2):171-5.

[32] Kuhn, KD .: **PMMA Cements**. Springer-Verlag, Berlin. 2014, p 195.

[33] Morita S, Yamamoto H, Furuya K, Ishihara K, Nakabayashi N.: E**nhanced strength in cemented stem fixation using adhesive acrylic cement as a metal coating material.** *J Biomed Mater Res.* 1997 Feb;34(2):171-5.

[34] Morita S, Yamamoto H, Furuya K, Ishihara K, Nakabayashi N.: E**nhanced strength in cemented stem fixation using adhesive acrylic cement as a metal coating material.** *J Biomed Mater Res.* 1997 Feb;34(2):171-5.

[35] Billi F., Kavanaugh, A., Schmalzreid, H., Schmalzreid, T.: **Factors influence of the Initial Strength of the Tibial Tray-PMMA Cement Bond.** *ORS 2014,* Poster No. 1854.

[36] Stone MH, Wilkinson R, Stother IG.: **Some factors affecting the strength of the cement-metal interface**. *J Bone Joint Surg Br.* 1989 Mar;71(2):217-21.
[37] Wang T, Pelletier MH, Bertollo N, Crosky A, Walsh WR.: **Cement-implant interface contamination: possible reason of inferior clinical outcomes for rough surface cemented stems.** *Open Orthop J.* 2013 Jun 28;7:250-7.
[38] Raab S, Ahmed AM, Provan JW.: **The quasistatic and fatigue performance of the implant/bone-cement interface.** *J Biomed Mater Res.* 1981 Mar;15(2):159-82.
[39] Raab S, Ahmed AM, Provan JW.: **Thin film PMMA precoating for improved implant bone-cement fixation**. *J Biomed Mater Res.* 1982 Sep;16(5):679-704.
[40] Cook SD, Thongpreda N, Anderson RC, Thomas KA, Haddad RJ Jr, Griffin CD.: **Optimum pore size for bone cement fixation**. *Clin Orthop Relat Res.* 1987 Oct;(223):296-302.
[41] Bundy, K. J. & Penn, R. W.: **The effect of surface preparation on metal/bone cement interfacial strength**. *J.Biomed. Mater. Res.,* 21 (1987) 773-805.
[42] Davies JP, Harris WH.: **Strength of cement-metal interfaces in fatigue: comparison of smooth, porous and precoated specimens**. *Clin Mater.* 1993;12(2):121-6.
[43] Davies JP, Harris WH.: **Strength of cement-metal interfaces in fatigue: comparison of smooth, porous and precoated specimens**. *Clin Mater.* 1993;12(2):121-6.
[44] Raab S, Ahmed AM, Provan JW.: **Thin film PMMA precoating for improved implant bone-cement fixation**. *J Biomed Mater Res.* 1982 Sep;16(5):679-704.
[45] Crowninshield RD, Jennings JD, Laurent ML, Maloney WJ.:**Cemented femoral component surface finish mechanics.** *Clin Orthop Relat Res.* 1998 Oct;(355):90-102.
[46] Crowninshield RD, Jennings JD, Laurent ML, Maloney WJ.:**Cemented femoral component surface finish mechanics.** *Clin Orthop Relat Res.* 1998 Oct;(355):90-102.
[47] Zhao W, Barsun S, Ramani K, Johnson T, King R, Lin S.: **Development of PMMA-precoating metal prostheses via injection molding: residual stresses.** *J Biomed Mater Res.* 2001;58(4):456-62.
[48] Sporer SM, Callaghan JJ, Olejniczak JP, Goetz DD, Johnston RC.: **The effects of surface roughness and polymethylmethacrylate precoating on the radiographic and clinical results of the Iowa hi prosthesis. A study of patients less than fifty years old.***J Bone Joint Surg Am*. 1999 Apr;81(4):481-92.
[49] Foran JR, Whited BW, Sporer SM.: **Early aseptic loosening with a precoated low-profile tibial component: a case series**. *J Arthroplasty.* 2011 Dec;26(8):1445-50.
[50] Crowninshield RD, Jennings JD, Laurent ML, Maloney WJ.: **Cemented femoral component surface finish mechanics.** *Clin Orthop Relat Res.* 1998 Oct;(355):90-102.
[51] Crowninshield RD, Jennings JD, Laurent ML, Maloney WJ.:**Cemented femoral component surface finish mechanics.** *Clin Orthop Relat Res.* 1998 Oct;(355):90-102.
[52] Davies JP, Harris WH.: **Strength of cement-metal interfaces in fatigue: comparison of smooth, porous and precoated specimens**. *Clin Mater.* 1993;12(2):121-6.
[53] Davies JP, Harris WH.: **Strength of cement-metal interfaces in fatigue: comparison of smooth, porous and precoated specimens**. *Clin Mater.* 1993;12(2):121-6.
[54] Pittman GT, Peters CL, Hines JL, Bachus KN.: **Mechanical bond strength of the cement-tibial component interface in total knee arthroplasty.** *J Arthroplasty.* 2006 Sep;21(6):883-8.
[55] Raab S, Ahmed AM, Provan JW.: **Thin film PMMA precoating for improved implant bone-cement fixation**. *J Biomed Mater Res.* 1982 Sep;16(5):69-704.
[56] Pittman GT, Peters CL, Hines JL, Bachus KN.: **Mechanical bond strength of the cement-tibial component interface in total knee arthroplasty**. *J Arthroplasty.* 2006 Sep;21(6):883-8

[57] Grupp TM, Saleh KJ, Holderied M, Pfaff AM, Schilling C, Schroeder C, Mihalko WM.: **Primary stability of tibial plateaus under dynamic compression-shear loading in human tibiae - Influence of keel length, cementation area and tibial stem**. *J Biomech.* 2017 Jul 5;59:9-22.
[58] Grupp TM, Saleh KJ, Holderied M, Pfaff AM, Schilling C, Schroeder C, Mihalko WM.: **Primary stability of tibial plateaus under dynamic compression-shear loading in human tibiae - Influence of keel length, cementation area and tibial stem**. *J Biomech.* 2017 Jul 5;59:9-22.
[59] Cook SD, Thongpreda N, Anderson RC, Thomas KA, Haddad RJ Jr, Griffin CD.: **Optimum pore size for bone cement fixation**. *Clin Orthop Relat Res.* 1987 Oct;(223):296-302.
[60] Pittman GT, Peters CL, Hines JL, Bachus KN.: **Mechanical bond strength of the cement-tibial component interface in total knee arthroplasty.** *J Arthroplasty.* 2006 Sep;21(6):883-8.
[61] Raab S, Ahmed AM, Provan JW.: **Thin film PMMA precoating for improved implant bone-cement fixation**. *J Biomed Mater Res.* 1982 Sep;16(5):69-704.
[62] Pittman GT, Peters CL, Hines JL, Bachus KN.: **Mechanical bond strength of the cement-tibial component interface in total knee arthroplasty.** *J Arthroplasty.* 2006 Sep;21(6):883-8.
[63] Pittman GT, Peters CL, Hines JL, Bachus KN.: **Mechanical bond strength of the cement-tibial component interface in total knee arthroplasty.** *J Arthroplasty.* 2006 Sep;21(6):883-8.
[64] Cook SD, Thongpreda N, Anderson RC, Thomas KA, Haddad RJ Jr, Griffin CD.: **Optimum pore size for bone cement fixation**. *Clin Orthop Relat Res.* 1987 Oct;(223):296-302.
[65] Raab S, Ahmed AM, Provan JW.: **Thin film PMMA precoating for improved implant bone-cement fixation**. *J Biomed Mater Res.* 1982 Sep;16(5):69-704.
[66] Davies JP, Harris WH.: **Strength of cement-metal interfaces in fatigue: comparison of smooth, porous and precoated specimens**. *Clin Mater.* 1993;12(2):121-6.
[67] Raab S, Ahmed AM, Provan JW.: **Thin film PMMA precoating for improved implant bone-cement fixation**. *J Biomed Mater Res.* 1982 Sep;16(5):69-704.
[68] Cook SD, Thongpreda N, Anderson RC, Thomas KA, Haddad RJ Jr, Griffin CD.: **Optimum pore size for bone cement fixation**. *Clin Orthop Relat Res.* 1987 Oct;(223):296-302.
[69] Cerquiglini A, Henckel J, Hothi H, Allen P, Lewis J, Eskelinen A, Skinner J, Hirschmann MT, Hart AJ: **Analysis of the Attune tibial Tray backside: a comparative retrieval study**. *Bone Joint Res*. 2019;8(3):136–145.
[70] Torino D, Damsgaard C, Kolessar D J, Hayes DS, Foster B, Constantino J, Grahanm J: **Tibial Baseplate-Cement Interface Debonding in the Attune Total Knee Arthroplasty System**. *Arthroplasty Today.* 2022 Sep 20;17:165-171.
[71] Cerquiglini A, Henckel J, Hothi H, Allen P, Lewis J, Eskelinen A, Skinner J, Hirschmann MT, Hart AJ: **Analysis of the Attune tibial Tray backside: a comparative retrieval study**. *Bone Joint Res*. 2019;8(3):136–145.
[72] Bonutti PM, Khlopas A, Chughtai M, Cole C, Gwam CU, Harwin SF, Whited B, Omiyi DE, Drumm JE: **Unusually High Rate of Early Failure of Tibial Component in ATTUNE Total Knee Arthroplasty System at Implant-Cement Interface**. *J Knee Surg.* 2017 Jun;30(5):435-439.
[73] Arsoy D, Pagnano MW, Lewallen DG, Hanssen AD, Sierra RJ.: **Aseptic tibial debonding as a cause of early failure in a modern total knee arthroplasty desig**n. *Clin Orthop Relat Res.* 2013 Jan;471(1):94-101.
[74] Cerquiglini A, Henckel J, Hothi H, Allen P, Lewis J, Eskelinen A, Skinner J, Hirschmann MT, Hart AJ[1].:**Analysis of the Attune tibial tray backside: A comparative retrieval study.** *Bone Joint Res.* 2019 Apr 2;8(3):136-145.
[75] Bonutti PM, Khlopas A, Chughtai M, Cole C, Gwam CU, Harwin SF, Whited B, Omiyi DE, Drumm JE.: **Unusually High Rate of Early Failure of Tibial Component in ATTUNE Total Knee Arthroplasty System at Implant-Cement Interface**. *J Knee Surg.* 2017 Jun;30(5):435-439.

[76] Cheng K, Pruitt L, Zaloudek C, Ries MD.: **Osteolysis caused by tibial component debonding in total knee arthroplasty.** *Clin Orthop Relat Res.* 2006 Feb;443:333-6.
[77] Foran JR, Whited BW, Sporer SM.: **Early aseptic loosening with a precoated low-profile tibial component: a case serie**s. *J Arthroplasty.* 2011 Dec;26(8):1445-50.
[78] Ries C, Heinichen M, Dietrich F, Jakubowitz E, Sobau C, Heisel C.: **Short-keeled cemented tibial components show an increased risk for aseptic loosening.** *Clin Orthop Relat Res.* 2013 Mar;471(3):1008-13.
[79] Behnam, Y., Maso, JB., Wilson, H.,Rullkoetter, P., Clar, C.: **Knee Balance Assessment during Cementation is Detrimental to Initial Tibial Tray Fixation.** *ORS 2018 Annual Meeting Paper No.0192.*
[80] Kelly MP, Illgen RL, Chen AF, Nam D.: **Trends in the Use of High-Viscosity Cement in Patients Undergoing Primary Total Knee Arthroplasty in the United States.** *J Arthroplasty.* 2018 Nov;33(11):3460-3464.
[81] Kelly BC, Owen JR, Shah SC, Johnson AJ, Golladay GJ, KatesSL: **A Biomechanical Comparison of the Effect of Baseplate Design and Bone Marrow Fat Infiltration on Tibial Baseplate Pullout Strength.** *J Arthroplasty* 2021 Jan;36(1):356-361.
[82] Maag C, Peckenpaugh E, Metcalf A. Heldreth M: **Influence Of Intraoperative Lipid /Marrow Infiltration And Intraoperative Motions Upon Cemented Tibial Implant Fixation. [**Abstract]. *18th EFORT Congress*. Vienna, Austria, 2017 (also AAOS 2019). *Also 'ATTUNE S+™Technology – Addressing Intraoperative Motion & Lipids: Summary of the Science' , DePuy Poster 169683-210308 GLBL by Mark Heldreth et al.*
[83] Rebgetz P, Kovacs A, Bochat K, Hayes A, Clark G, Blakeney W, Pabbruwe M: L**oosening of tibia baseplates after total knee arthroplasty: Evaluation of pull-out strength of tibia baseplate-cement Interface.** *Clin Biomech (Bristol, Avon).* 2021 Dec;90:105497.
[84] Jaeger S, Eissler M, Schwarze M, Schonhoff M, Kretzer JP, Bitshc RG: **Does tibial design modification improve implant stability for total knee arthroplasty? An experimental cadaver study.** *Bone Joint Res.* 2022 Apr;11(4):229-238.
[85] Martin JR, Wronski PT, Schilkowsky RM, Orfanos AV, Fehring TK, Mason JB.**Motion During Total Knee Cementing Significantly Decreases Tibial Implant Fixation Strength.** *J Arthroplasty.* 2022 Jun;37(6S):S12-S18.
[86] Kelly BC, Owen JR, Shah SC, Johnson AJ, Golladayt GJ, Kates SL: **A Biomechanical Comparison of the Effect of Baseplate Design and Bone Marrow Fat Infiltration on Tibial Baseplate Pullout Strength** .*J Arthroplasty*. 2021 Jan;36(1):356-361.
[87] Kelly BC, Owen JR, Shah SC, Johnson AJ, Golladayt GJ, Kates SL: **A Biomechanical Comparison of the Effect of Baseplate Design and Bone Marrow Fat Infiltration on Tibial Baseplate Pullout Strength** .*J Arthroplasty*. 2021 Jan;36(1):356-361.
[88] Bonutti PM, Khlopas A, Chughtai M, Cole C, Gwam CU, Harwin SF, Whited B, Omiyi DE, Drumm JE.: **Unusually High Rate of Early Failure of Tibial Component in ATTUNE Total Knee Arthroplasty System at Implant-Cement Interface**. *J Knee Surg.* 2017 Jun;30(5):435-439.
[89] Hazelwood KJ, O'Rourke M, Stamos VP, McMillan RD, Beigler D Robb WJ: **Case series report: early cementimplant interface fixation failure in total knee replacement.** *Knee* 2015;22:424–428.
[90] Rebgetz P, Kovacs A, Bochat K, Hayes A, Clark G, Blakeney W, Pabbruwe M: L**oosening of tibia baseplates after total knee arthroplasty: Evaluation of pull-out strength of tibia baseplate-cement Interface.** *Clin Biomech (Bristol, Avon).* 2021 Dec;90:105497.

[91] Murphy JD, Braunlich PR, Judson WR, Harker JN, Baumann PA: **Early Aseptic Failure of the Tibial Component- Cement Interface in ATTUNE® Total Knee Arthroplasty: A Report of Three Cases** *Cureus*.2021 Dec 21;13(12):e20582.

[92] Ranawat CS, White PB, West S, Ranawat AS: **Clinical and Radiographic Results of Attune and PFC Sigma Knee Designs at 2-Year Follow-Up: A Prospective Matched-Pair Analysis**.*J Arthroplasty*. 2017 Feb;32(2):431-436.

[93] Willburger RE, Oberberg S**: Early and mid-term results with the ATTUNE total knee replacement system compared to PFC Sigma: a prospective comparative study**. *J Orthop Surg Res.* 2022 Nov 24;17(1):509.

[94] Giaretta S, Berti M, Micheloni GM, Ceccato A, Marangoni F, Momoli A: **Early experience with the ATTUNE Total Knee Replacement System.** *Acta Biomed* 2019 Oct 29;90(12-S):98-103.

[95] Billi F, Kavanaugh A, Schmalzried H, Schmalzried TP. **Techniques for improving the initial strength of the tibial tray-cement interface bond.** *Bone Joint J* 2019 Jan;101-B(1_Supple_A):53-58.

[96] Cerquiglini A, Henckel J, Hothi H, Allen P, Lewis J, Eskelinen A, Skinner J, Hirschmann MT, Hart AJ: **Analysis of the Attune tibial Tray backside: a comparative retrieval study**. *Bone Joint Res*. 2019;8(3):136–145.

[97] Cerquiglini A, Henckel J, Hothi H, Allen P, Lewis J, Eskelinen A, Skinner J, Hirschmann MT, Hart AJ: **Analysis of the Attune tibial Tray backside: a comparative retrieval study**. *Bone Joint Res*. 2019;8(3):136–145.

[98] Hazelwood KJ, O'Rourke M, Stamos VP, McMillan RD, Beigler D Robb WJ: **Case series report: early cementimplant interface fixation failure in total knee replacement.** *Knee* 2015;22:424–428.

[99] Kopinski JE, Aggarwal A, Nunley RM, Barrack RL, Nam D: **Failure at the tibial cement–implant interface with the use of high-viscosity cement in total knee arthroplasty**. *J Arthroplasty* 2016;31:2579–2582.

[100] Cerquiglini A, Henckel J, Hothi H, Allen P, Lewis J, Eskelinen A, Skinner J, Hirschmann MT, Hart AJ: **Analysis of the Attune tibial Tray backside: a comparative retrieval study**. *Bone Joint Res*. 2019;8(3):136–145.

[101] Buller LT, Rao V, Chiu YF, Nam D, McLawhorn AS. **Primary total knee arthroplasty performed using high-viscosity cement is associated with higher odds of revision for aseptic loosening**. J Arthroplasty 2020;35:S182e9.

[102] Elliott R, Regazzola G, Bruce WJM. **Ambient theatre temperature and cement setting time in total knee arthroplasty**. ANZ J Surg 2019;89:1424e7.

[103] Refsum AM, Nguyen UV, Gjertsen J-E, Espehaug B, Fenstad AM, Lein RK, et al.**Cementing technique for primary knee arthroplasty: a scoping review.** Acta Orthop 2019;90:582.

[104] Hegde V, Bracey DN, Johnson RM, Dennis DA, Jennings JM. **Tourniquet use improves cement penetration and reduces radiolucent line progression at 5 years after total knee arthroplasty**. J Arthroplasty 2021;36:S209e14.

[105] Torino D, Damsgaard C, Kolessar D J, Hayes DS, Foster B, Constantino J, Grahanm J: **Tibial Baseplate-Cement Interface Debonding in the Attune Total Knee Arthroplasty System**. *Arthroplasty Today.* 2022 Sep 20;17:165-171.

[106] Refsum AM, Nguyen UV, Gjertsen J-E, Espehaug B, Fenstad AM, Lein RK, et al.**Cementing technique for primary knee arthroplasty: a scoping review.** Acta Orthop 2019;90:582.

[107] Hegde V, Bracey DN, Johnson RM, Dennis DA, Jennings JM. **Tourniquet use improves cement penetration and reduces radiolucent line progression at 5 years after total knee arthroplasty**. J Arthroplasty 2021;36:S209e14.

[108] Sun C, Yang X, Zhang X, Ma Q, Yu P, Cai X, Zhou Y: **The impact of tourniquet on tibial bone cement penetration in different zones in primary total knee arthroplasty: a meta-analysis.***J Orthop Surg Res*. 2021 Mar 17;16(1):198.

[109] Cerquiglini A, Henckel J, Hothi H, Allen P, Lewis J, Eskelinen A, Skinner J, Hirschmann MT, Hart AJ: **Analysis of the Attune tibial Tray backside: a comparative retrieval study**. *Bone Joint Res*. 2019;8(3):136–145.

[110] Cerquiglini A, Henckel J, Hothi H, Allen P, Lewis J, Eskelinen A, Skinner J, Hirschmann MT, Hart AJ: **Analysis of the Attune tibial Tray backside: a comparative retrieval study**. *Bone Joint Res*. 2019;8(3):136–145.

[111] Cerquiglini A, Henckel J, Hothi H, Allen P, Lewis J, Eskelinen A, Skinner J, Hirschmann MT, Hart AJ: **Analysis of the Attune tibial Tray backside: a comparative retrieval study**. *Bone Joint Res*. 2019;8(3):136–145.

[112] Kelly BC, Owen JR, Shah SC, Johnson AJ, Golladay GJ, KatesSL: **A Biomechanical Comparison of the Effect of Baseplate Design and Bone Marrow Fat Infiltration on Tibial Baseplate Pullout Strength.** *J Arthroplasty* 2021 Jan;36(1):356-361.

[113] Maag C, Peckenpaugh E, Metcalf A. Heldreth M: **Influence Of Intraoperative Lipid /Marrow Infiltration And Intraoperative Motions Upon Cemented Tibial Implant Fixation. [**Abstract]. *18th EFORT Congress*. Vienna, Austria, 2017 (also AAOS 2019). *Also 'ATTUNE S+™Technology – Addressing Intraoperative Motion & Lipids: Summary of the Science' , DePuy Poster 169683-210308 GLBL by Mark Heldreth et al.*

[114] Billi F, Kavanaugh A, Schmalzried H, Schmalzried TP. **Techniques for improving the initial strength of the tibial tray-cement interface bond.** *Bone Joint J* 2019 Jan;101-B(1_Supple_A):53-58.

[115] Kaptein BL, den Hollander P, Thomassen B, Fiocco M, Nelissen GHH: **A randomized controlled trial comparing tibial migration of the ATTUNE cemented cruciate-retaining knee prosthesis with the PFC-sigma design**. *Bone Joint J.* 2020 Sep;102-B(9):1158-1166.

[116] Kaptein BL, den Hollander P, Thomassen B, Fiocco M, Nelissen GHH: **A randomized controlled trial comparing tibial migration of the ATTUNE cemented cruciate-retaining knee prosthesis with the PFC-sigma design**. *Bone Joint J.* 2020 Sep;102-B(9):1158-1166.

[117] Rebgetz P, Kovacs A, Bochat K, Hayes A, Clark G, Blakeney W, Pabbruwe M: **Loosening of tibia baseplates after total knee arthroplasty: Evaluation of pull-out strength of tibia baseplate-cement Interface.** *Clin Biomech (Bristol, Avon).* 2021 Dec;90:105497.

[118] Rebgetz P, Kovacs A, Bochat K, Hayes A, Clark G, Blakeney W, Pabbruwe M: **Loosening of tibia baseplates after total knee arthroplasty: Evaluation of pull-out strength of tibia baseplate-cement Interface.** *Clin Biomech (Bristol, Avon).* 2021 Dec;90:105497.

[119] Kelly BC, Owen JR, Shah SC, Johnson AJ, Golladayt GJ, Kates SL: **A Biomechanical Comparison of the Effect of Baseplate Design and Bone Marrow Fat Infiltration on Tibial Baseplate Pullout Strength** .*J Arthroplasty*. 2021 Jan;36(1):356-361.

[120] Jaeger S, Eissler M, Schwarze M, Schonhoff M, Kretzer JP, Bitshc RG: **Does tibial design modification improve implant stability for total knee arthroplasty? An experimental cadaver study.** *Bone Joint Res.* 2022 Apr;11(4):229-238.

[121] Rebgetz P, Kovacs A, Bochat K, Hayes A, Clark G, Blakeney W, Pabbruwe M: **Loosening of tibia baseplates after total knee arthroplasty: Evaluation of pull-out strength of tibia baseplate-cement Interface.** *Clin Biomech (Bristol, Avon).* 2021 Dec;90:105497.

[122] Staats K, Wannmacher T, Weihs V, Koller U, Kubista B, Windhagert R: **Modern cemented total knee arthroplasty design shows a higher incidence of radiolucent lines compared to its predecessor**. *Knee Surg Sports Traumatol Arthrosc.* 2019;27(4):1148–1155.

[123] Sadauskas A, Engh C, Mehta M, Levine B: **Implant Interface Debonding After Total Knee Arthroplasty: A New Cause for Concern?** *Arthroplasty Today*. 2020 Dec 5;6(4):972-975.
[124] Sadauskas A, Engh C, Mehta M, Levine B: **Implant Interface Debonding After Total Knee Arthroplasty: A New Cause for Concern?** *Arthroplasty Today*. 2020 Dec 5;6(4):972-975.
[125] Sadauskas A, Engh C, Mehta M, Levine B: **Implant Interface Debonding After Total Knee Arthroplasty: A New Cause for Concern?** *Arthroplasty Today*. 2020 Dec 5;6(4):972-975.
[126] Rodríguez-Collell JR, Mifsut D, Ruiz-Sauri A, Rodríguez-Pino L, González-Soler EM, Valverde-Navarro AA: **Improving the cementation of the tibial component in knee arthroplasty**. *Bone Joint Res.* 2021 Aug;10(8):467-473.
[127] Grupp TM, Saleh KJ, Holderied M, Pfaff AM, Schilling C, Schroeder C, Mihalko WM: **Primary stability of tibial plateaus under dynamic compression-shear loading in human tibiae - Influence of keel length, cementation area and tibial stem**. *J Biomech.* 2017;59:9–22.
[128] Peters CL, Craig MA, Mohr RA, Bachus KN:**Tibial component fixation with cement: full- versus surface-cementation techniques.** *Clin Orthop Relat Res.* 2003;409:158–168.
[129] Peters CL, Craig MA, Mohr RA, Bachus KN:**Tibial component fixation with cement: full- versus surface-cementation techniques.** *Clin Orthop Relat Res.* 2003;409:158–168.
[130] Martin JR, Wronski PT, Schilkowsky RM, Orfanos AV, Fehring TK, Mason JB.**Motion During Total Knee Cementing Significantly Decreases Tibial Implant Fixation Strength.** *J Arthroplasty.* 2022 Jun;37(6S):S12-S18.
[131] Martin JR, Wronski PT, Schilkowsky RM, Orfanos AV, Fehring TK, Mason JB.**Motion During Total Knee Cementing Significantly Decreases Tibial Implant Fixation Strength.** *J Arthroplasty.* 2022 Jun;37(6S):S12-S18.
[132] Martin JR, Wronski PT, Schilkowsky RM, Orfanos AV, Fehring TK, Mason JB.**Motion During Total Knee Cementing Significantly Decreases Tibial Implant Fixation Strength.** *J Arthroplasty.* 2022 Jun;37(6S):S12-S18.
[133] Martin JR, Wronski PT, Schilkowsky RM, Orfanos AV, Fehring TK, Mason JB.**Motion During Total Knee Cementing Significantly Decreases Tibial Implant Fixation Strength.** *J Arthroplasty.* 2022 Jun;37(6S):S12-S18.
[134] Buller LT, Rao V, Chiu YF, Nam D, McLawhorn AS. **Primary total knee arthroplasty performed using high-viscosity cement is associated with higher odds of revision for aseptic loosening**. J Arthroplasty 2020;35:S182e9.
[135] Bonutti PM, Khlopas A, Chughtai M, Cole C, Gwam CU, Harwin SF, Whited B, Omiyi DE, Drumm JE.: **Unusually High Rate of Early Failure of Tibial Component in ATTUNE Total Knee Arthroplasty System at Implant-Cement Interface**. *J Knee Surg.* 2017 Jun;30(5):435-439.
[136] Sadoghi P, Pawelka W, Liebensteiner MC, Williams A, Leithner A, Labek G.: *The incidence of implant fractures after total hip arthroplasty. Int Orthop. 2014 Jan;38(1):39-46.*
[137] Labek G, Neumann D, Agreiter M, Schuh R, Böhler N.: **Impact of implant developers on published outcome and reproducibility of cohort-based clinical studies in arthroplasty**.*J Bone Joint Surg Am.* 2011 Dec 21;93 Suppl 3:55-61.
[138] Lewis PL, Graves SE, de Steiger RN, Campbell DG, Peng Y, Hatton A, Lorimer M: **Does Knee Prosthesis Survivorship Improve When Implant Designs Change? Findings from the Australian Orthopaedic Association National Joint Replacement Registry.** *Clin Orthop Relat Res* 2020 Jun;478(6):1156-1172.
[139]Labek G, Janda W, Agreiter M, Schuh R, Böhler N.: **Organisation, data evaluation, interpretation and effect of arthroplasty register data on the outcome in terms of revision rate in total hip arthroplasty.** *Int Orthop*. 2011 Feb;35(2):157-63. doi: 10.1007/s00264-010-1131-4. Epub 2010 Oct 5.

[140] **An Instructional Aid for Occupational Safety and Health in Mechanical Engineering Design,** *ASME Safety Division under the sponsorship of the National Institute for Occupational Safety and Health*, ASME, 1984.

[141] Main, Bruce: **Risk Assessment Challenges and Opportunities**, Design Safety Engineering Inc., 2012, Chapters 5-8.

[142] **An Instructional Aid for Occupational Safety and Health in Mechanical Engineering Design,** *ASME Safety Division under the sponsorship of the National Institute for Occupational Safety and Health*, ASME, 1984.

[143] Torino D, Damsgaard C, Kolessar D J, Hayes DS, Foster B, Constantino J, Grahanm J: **Tibial Baseplate-Cement Interface Debonding in the Attune Total Knee Arthroplasty System**. *Arthroplasty Today.* 2022 Sep 20;17:165-171.

[144] Rob Packard, BonZone Article, http://www.bonezonepub.com/component/content/article/958-how-far-is-possible-for-medical-device-risk-management

[145]Lavernia CJ, Contreras JS, Parvizi J, Sharkey PF, Barrack R, Rossi MD.: **Do patient expectations about arthroplasty at initial presentation for hip or knee pain differ by sex and ethnicity?** *Clin Orthop Relat Res.* 2012 Oct;470(10):2843-53.

[146] FORCE-TJR ANNUAL REPORT 2014, (Function and Outcomes Research for Comparative Effectiveness in Total Joint Replacement), University of Massachusetts Medical School, Department of Orthopedics and Physical Rehabilitation, www.force-tjr.org.

[147] Canadian Joint Replacement Registry, Canadian Institute for Health Information, 2007& 2008.

[148] **Heck DA, Robinson RL, Partridge CM, Lubitz RM, Freund DA.:** Patient outcomes after knee replacement**.** ***Clin Orthop Relat Res.*** **1998 Nov;(356):93-110.**

[149] Anthropometric Reference Data for Children and Adults: United States, 1988-1994, 1999-2002,2003-2006, 2007-2010, **U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES, Centers for Disease Control and Prevention, National Center for Health Statistics. (*4 separate publications. First authors Fryar, CD, and McDowell, MA*.)**

[150] Bang H, Chiu YL, Memtsoudis SG, Mandl LA, Della Valle AG, Mushlin AI, Marx RG, Mazumdar M.: **Total hip and total knee arthroplasties: trends and disparities revisited.** *Am J Orthop* (Belle Mead NJ). 2010 Sep;39(9):E95-102.

[151] McLaughlin JR, Lee KR.: **The outcome of total hip replacement in obese and non-obese patients at 10- to 18-years.** J Bone Joint Surg Br. 2006 Oct;88(10):1286-92.

[152] McCalden RW, Charron KD, MacDonald SJ, Bourne RB, Naudie DD. **Does morbid obesity affect the outcome of total hip replacement?: an analysis of 3290 THRs**. J Bone Joint Surg Br. 2011 Mar;93(3):321-5.

[153] McDonald, J., Huo, M.: T**otal hip replacement: unique challenges in the obese and geriatric populations.** *Current Opinion in Orthopaedics* 2008, 19:33– 36.

[154] Yeung E, Jackson M, Sexton S, Walter W, Zicat B, Walter W. **The effect of obesity on the outcome of hip and knee arthroplasty**. Int Orthop. 2010 May 29. [Epub ahead of print]

[155] Hip and Knee Arthroplasty Annual Report 2017, Australian Orthopaedic Association National Joint Replacement Registry. http://www.dmac.adelaide.edu.au/aoanjrr/publications.jsp

[156] Benson LC, DesJardins JD, Harman MK, LaBerge M.: **Effect of stair descent loading on ultra-high molecular weight polyethylene wear in a force-controlled knee simulator.** Proc Inst Mech Eng [H]. 2002; 216(6): 409-18.

[157] Costigan PA, Deluzio KJ, Wyss UP.: **Knee and hip kinetics during normal stair climbing**. *Gait Posture*. 2002 Aug; 16(1): 31-7.

[158] Harrison, R., Lees, R., McCullagh, P., and Rowe, W.: **A Bioengineering Analysis of Human Muscle and Joint Forces in the Lower Limbs During Running**. *Journal of Sports Sciences*, 1986, 4; 201-218.

[159] Ellis, M., Seedhom, B., and Wright, V.: **Forces in the Knee Joint Whilst Rising From a Seated Position**. *Journal of Biomedical Engineering*, ,1984, 6: 113-120.

[160] Paul, J., and McGrouther,D.: **Forces Transmitted at the Hip and Knee Joint of Normal and Disabled Persons During a Range of Activities**. *Acta Orthopaedica Belgica* , 1975, 41:1:78-88.

[161] Seireg, A., and Arvikar, R.: **The Prediction of Muscular Load Sharing and Joint Forces in the Lower Extremities During Walking**. *J. Biomechanics,* 1975; 8:89-102**.**

[162] Wimmer MA, Andriacchi TP.: **Tractive forces during rolling motion of the knee: implications for wear in total knee replacement**. *J Biomech*. 1997 Feb; 30(2): 131-7.

[163] Morlock, M., Bluhm, A., Vollmer, M., Müller, V., Honl, M., Hille, E.,Schneider, E. and Bergmann, G. **Quantification of Duration and Frequency of everyday activities in total hip patients with a mini computer system**, *Book of Abstracts, International Society of Biomechanics XVIIth Congress*, p. 84,1999.

[164] Schmalzried, T., et al., **Factors correlating with long term survival of McKee-Farrar total hip prostheses***. Clin-Orthop*, 1996. 329Suppl: p.S48,-59.

[165] Seedhom, B. and N. Wallbridge, **Walking activities and wear of prostheses.** *Annals of the Rheumatic Diseases*, 1985. 44(12): p. 838-843.

[166] Morlock, M. , Schneider, E. , Bluhm, A. Vollmer, M. Bergmann, G. Müller, V. Honl, M.: **Duration and frequency of everyday activities in total hip patients** *J Biomech.* 2001 Jul;34(7): 873-81.

[167] Bergmann G, Graichen F, Rohlmann A, Bender A, Heinlein B, Duda GN, Heller MO, Morlock MM. **Realistic loads for testing hip implants.** *Biomed Mater Eng.* 2010;20(2):65-75.

[168] Morlock, M., Bluhm, A., Vollmer, M., Müller, V., Honl, M., Hille, E.,Schneider, E. and Bergmann, G. **Quantification of Duration and Frequency of everyday activities in total hip patients with a mini computer system**, *Book of Abstracts, International Society of Biomechanics XVIIth Congress*, p. 84,1999.

[169] Schmalzried, T., et al., **Factors correlating with long term survival of McKee-Farrar total hip prostheses***. Clin-Orthop*, 1996. 329Suppl: p.S48,-59.

[170] Seedhom, B. and N. Wallbridge, **Walking activities and wear of prostheses.** *Annals of the Rheumatic Diseases*, 1985. 44(12): p. 838-843.

[171] Morlock, M. , Schneider, E. , Bluhm, A. Vollmer, M. Bergmann, G. Müller, V. Honl, M.: **Duration and frequency of everyday activities in total hip patients** *J Biomech.* 2001 Jul;34(7): 873-81.

[172] Bennett D, Humphreys L, O'Brien S, Kelly C, Orr J, Beverland DE.: **Activity levels and polyethylene wear of patients 10 years post hip replacement.** *Clin Biomech (Bristol, Avon).* 2008 Jun;23(5):571-6. Epub 2008 Feb 5.

[173] Borque KA, Gold JE, Incavo SJ, Patel RM, Ismaily SE, Noble PC.; **Anteroposterior Knee Stability During Stair Descent.** *J Arthroplasty*. 2015 Jun;30(6):1068-72. doi: 10.1016/j.arth.2015.01.011. Epub 2015 Jan 21

[174] Borque KA, Gold JE, Incavo SJ, Patel RM, Ismaily SE, Noble PC.: **Anteroposterior Knee Stability During Stair Descent**. *J Arthroplasty.* 2015 Jun;30(6):1068-72.

[175] Borque KA, Gold JE, Incavo SJ, Patel RM, Ismaily SE, Noble PC.: **Anteroposterior Knee Stability During Stair Descent**. *J Arthroplasty.* 2015 Jun;30(6):1068-72.

[176] Kutzner I, Heinlein B, Graichen F, Bender A, Rohlmann A, Halder A, Beier A, Bergmann G.: **Loading of the knee joint during activities of daily living measured in vivo in five subjects**. *J Biomech.* 2010 Aug 10;43(11):2164-73.

[177] Heinlein B, Kutzner I, Graichen F, Bender A, Rohlmann A, Halder AM, Beier A, Bergmann G.: **ESB Clinical Biomechanics Award 2008: Complete data of total knee replacement loading for level walking and stair climbing measured in vivo with a follow-up of 6-10 months**.*Clin Biomech (Bristol, Avon*). 2009 May;24(4):315-26. Epub 2009 Mar 13.

[178] Kutzner I, Damm P, Heinlein B, Dymke J, Graichen F, Bergmann G.: **The effect of laterally wedged shoes on the loading of the medial knee compartment-in vivo measurements with instrumented knee implants.***J Orthop Res.* 2011 Dec;29(12):1910-5. doi: 10.1002/jor.21477. Epub 2011 Jun 8.

[179] Varadarajan KM, Moynihan AL, D'Lima D, Colwell CW, Li G. **In vivo contact kinematics and contact forces of the knee after total knee arthroplasty during dynamic weight-bearing activities.***J Biomech.* 2008 Jul 19;41(10):2159-68. Epub 2008 Jun 5.

[180] D'Lima DD, Patil S, Steklov N, Colwell CW Jr.:**The 2011 ABJS Nicolas Andry Award: 'Lab'-in-a-knee: in vivo knee forces, kinematics, and contact analysis.** *Clin Orthop Relat Res.* 2011 Oct;469(10):2953-70. Epub 2011 May 20.

[181] Kutzner I, Heinlein B, Graichen F, Bender A, Rohlmann A, Halder A, Beier A, Bergmann G.: **Loading of the knee joint during activities of daily living measured in vivo in five subjects**. *J Biomech.* 2010 Aug 10;43(11):2164-73.

[182] Benson LC, DesJardins JD, Harman MK, LaBerge M.: **Effect of stair descent loading on ultra-high molecular weight polyethylene wear in a force-controlled knee simulator.** Proc Inst Mech Eng [H]. 2002; 216(6): 409-18.

[183] Baleani M, Cristofolini L, Viceconti M.: **Endurance testing of hip prostheses: a comparison between the load fixed in ISO 7206 standard and the physiological loads**. *Clin Biomech (Bristol, Avon).* 1999 Jun;14(5):339-45.

[184] Canadian Joint Replacement Registry, Canadian Institute for Health Information, 2007.

[185] Canadian Joint Replacement Registry, Canadian Institute for Health Information, 2007& 2008.

[186] Heck DA, Robinson RL, Partridge CM, Lubitz RM, Freund DA.: **Patient outcomes after knee replacement**. *Clin Orthop Relat Res.* 1998 Nov;(356):93-110.

[187] Anthropometric Reference Data for Children and Adults: United States, 1988-1994, 1999-2002,2003-2006, 2007-2010, 2011-2014; **U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES, Centers for Disease Control and Prevention, National Center for Health Statistics. (*4 separate publications. First authors Fryar, CD, and McDowell, MA*.)**

[188]Pérez-Blanca A, Prado M, Ezquerro F, Montañéz E, Espejo A.: **Addition of a short central extension to surface cemented tibial trays in primary TKA: an in vitro study of the effect on initial fixation stability and its relationship to supporting bone densit**y. *Clin Biomech (Bristol, Avon)*. 2008 May;23(4):483-92

[189] Peters CL, Craig MA, Mohr RA, Bachus KN.: **Tibial component fixation with cement: full- versus surface-cementation techniques**. *Clin Orthop Relat Res.* 2003 Apr;(409):158-68.

[190] Mündermann A, Dyrby CO, D'Lima DD, Colwell CW Jr, Andriacchi TP.: **In vivo knee loading characteristics during activities of daily living as measured by an instrumented total knee replacement.** *J Orthop Res.* 2008 Sep;26(9):1167-72.

[191] Mündermann A, Dyrby CO, D'Lima DD, Colwell CW Jr, Andriacchi TP.: **In vivo knee loading characteristics during activities of daily living as measured by an instrumented total knee replacement.** *J Orthop Res.* 2008 Sep;26(9):1167-72.

[192] Nagel K, Bishop NE, Schlegel UJ, Püschel K, Morlock MM.: **The Influence of Cement Morphology Parameters on the Strength of the Cement-Bone Interface in Tibial Tray Fixation.** *J Arthroplasty*. 2017 Feb;32(2):563-569.
[193] Nagel K, Bishop NE, Schlegel UJ, Püschel K, Morlock MM.: **The Influence of Cement Morphology Parameters on the Strength of the Cement-Bone Interface in Tibial Tray Fixation.** *J Arthroplasty*. 2017 Feb;32(2):563-569.
[194] Nagel K, Bishop NE, Schlegel UJ, Püschel K, Morlock MM.: **The Influence of Cement Morphology Parameters on the Strength of the Cement-Bone Interface in Tibial Tray Fixation.** *J Arthroplasty*. 2017 Feb;32(2):563-569.
[195] Nagel K, Bishop NE, Schlegel UJ, Püschel K, Morlock MM.: **The Influence of Cement Morphology Parameters on the Strength of the Cement-Bone Interface in Tibial Tray Fixation.** *J Arthroplasty*. 2017 Feb;32(2):563-569.
[196] Mann KA, Miller MA.: **Fluid-structure interactions in micro-interlocked regions of the cement-bone interface**.*Comput Methods Biomech Biomed Engin*. 2014;17(16):1809-20
[197] Miller MA, Goodheart JR, Khechen B, Janssen D, Mann KA.: **Changes in microgaps, micromotion, and trabecular strain from interlocked cement-trabecular bone interfaces in total knee replacements with in vivo service**. *J Orthop Res.* 2016 Jun;34(6):1019-25
[198] Miller MA, Goodheart JR, Khechen B, Janssen D, Mann KA.: **Changes in microgaps, micromotion, and trabecular strain from interlocked cement-trabecular bone interfaces in total knee replacements with in vivo service**. *J Orthop Res.* 2016 Jun;34(6):1019-25
[199] Miller MA, Goodheart JR, Khechen B, Janssen D, Mann KA.: **Changes in microgaps, micromotion, and trabecular strain from interlocked cement-trabecular bone interfaces in total knee replacements with in vivo service**. *J Orthop Res.* 2016 Jun;34(6):1019-25
[200] Srinivasan P, Miller MA, Verdonschot N, Mann KA, Janssen D.: **Strain shielding in trabecular bone at the tibial cement-bone interface.** *J Mech Behav Biomed Mater*. 2017 Feb;66:181-186.
[201] Miller MA, Goodheart JR, Khechen B, Janssen D, Mann KA.: **Changes in microgaps, micromotion, and trabecular strain from interlocked cement-trabecular bone interfaces in total knee replacements with in vivo service**. *J Orthop Res.* 2016 Jun;34(6):1019-25
[202] Shah KM, Wilkinson JM, Gartland A**.: Cobalt and chromium exposure affects osteoblast function and impairs the mineralization of prosthesis surfaces in vitro.** *J Orthop Res.* 2015 Nov;33(11):1663-70.
[203] Miller MA, Goodheart JR, Khechen B, Janssen D, Mann KA.: **Changes in microgaps, micromotion, and trabecular strain from interlocked cement-trabecular bone interfaces in total knee replacements with in vivo service**. *J Orthop Res.* 2016 Jun;34(6):1019-25
[204] Zimmerman WF, Miller MA, Cleary RJ, Izant TH, Mann KA.: **Damage in total knee replacements from mechanical overload**. *J Biomech.* 2016 Jul 5;49(10):2068-2075.
[205] Murase K, Crowninshield RD, Pedersen DR, Chang TS.: **An analysis of tibial component design in total knee arthroplasty.** *J Biomech*. 1983;16(1):13-22.
[206] **Walker, P.S., Thacher, J., Ewald, F., Milden, J.:** Variables affecting the cement stresses and the tilting of tibial components**. *27th Annual ORS,* Las Vegas, Nevada, February 24-26, 1981.**
[207] **Walker, P.S., Reilly, D., Ben-Div, M.:** Load transfer in the Upper tibia before and after tibial component attachment. ***26th Annual ORS*, Atlanta, Georgia, February 5-7, 1980.**
[208] **Stern SH, Wills D, Gilbert JL:** The effect of tibial stem design on component micromotion in knee arthroplasty.***Clin Orthop* 345:44, 1997.**
[209] **Hvid I.:** Trabecular bone strength at the knee. ***Clin Orthop Relat Res*. 1988 Feb;227:210-21. Review.**

[210] **Jazrawi LM, Bai B, Kummer FJ, Hiebert R, Stuchin SA.:** The effect of stem modularity and mode of fixation on tibial component stability in revision total knee arthroplasty**. *J Arthroplasty.* 2001 Sep;16(6):759-67.**

[211] Scott, CH, Biant, LC: **The role of the design of tibial components and stems in knee replacement** *J Bone Joint Surg Br* 2012;94-B:1009–15.

[212] Zimmerman WF, Miller MA, Cleary RJ, Izant TH, Mann KA.: **Damage in total knee replacements from mechanical overload**. *J Biomech.* 2016 Jul 5;49(10):2068-2075.

[213] Stern, SH., Will, RD., Gilbert, JL.: **The Effect of Tibial Stem Design on Component Micromotion in Knee Arthroplasty** , *Clin Orthop*. 345: 44-52.

[214] Ahmed AM, Tissakht M, Shrivastava SC, Chan K.: **Dynamic stress response of the implant/cement interface: an axisymmetric analysis of a knee tibial component**. *J Orthop Res.* 1990 May;8(3):435-47.

[215] Zimmerman WF, Miller MA, Cleary RJ, Izant TH, Mann KA.: **Damage in total knee replacements from mechanical overload**. *J Biomech.* 2016 Jul 5;49(10):2068-2075.

[216] Nagel K, Bishop NE, Schlegel UJ, Püschel K, Morlock MM.: **The Influence of Cement Morphology Parameters on the Strength of the Cement-Bone Interface in Tibial Tray Fixation.** *J Arthroplasty*. 2017 Feb;32(2):563-569.

[217] Stern, SH., Will, RD., Gilbert, JL.: **The Effect of Tibial Stem Design on Component Micromotion in Knee Arthroplasty** , *Clin Orthop*. 345: 44-52.

[218] Srinivasan P, Miller MA, Verdonschot N, Mann KA, Janssen D.: **Strain shielding in trabecular bone at the tibial cement-bone interface.** *J Mech Behav Biomed Mater*. 2017 Feb;66:181-186.

[219] Martin JR, Watts CD, Levy DL, Miner TM, Springer BD, Kim RH**.: Tibial Tray Thickness Significantly Increases Medial Tibial Bone Resorption in Cobalt-Chromium Total Knee Arthroplasty Implants.** J *Arthroplasty*. 2017 Jan;32(1):79-82

[220] Deen JT, Clay TB, Iams DA, Horodyski M, Parvataneni HK.: **Proximal tibial resorption in a modern total knee prosthesis.** *Arthroplast Today.* 2017 Dec 6;4(2):244-248.

[221] Martin JR, Watts CD, Levy DL, Kim RH.: **Medial tibial stress shielding: a limitation of cobalt chromium tibial baseplates**. *J Arthroplasty* 2017;32(2):558.

[222]Au AG, James Raso V, Liggins AB, Amirfazli A.: **Contribution of loading conditions and material properties to stress shielding near the tibial component of total knee replacements**. *J Biomech.* 2007;40(6):1410-6. Epub 2006 Jul 17

[223] Pilliar, R.M.; Lee, J.M.; Maniatopoulos, C. **Observations on the effect of movement on bone ingrowth into porous-surfaced implants.** *Clin. Orthop. Rel. Res.* 208:109-113; 1986.

[224] Stern, SH., Will, RD., Gilbert, JL.: **The Effect of Tibial Stem Design on Component Micromotion in Knee Arthroplasty** , *Clin Orthop*. 345: 44-52.

[225] Stern, SH., Will, RD., Gilbert, JL.: **The Effect of Tibial Stem Design on Component Micromotion in Knee Arthroplasty** , *Clin Orthop*. 345: 44-52.

[226] Mündermann A, Dyrby CO, D'Lima DD, Colwell CW Jr, Andriacchi TP.: **In vivo knee loading characteristics during activities of daily living as measured by an instrumented total knee replacement.** *J Orthop Res.* 2008 Sep;26(9):1167-72.

[227] Zimmerman WF, Miller MA, Cleary RJ, Izant TH, Mann KA.: **Damage in total knee replacements from mechanical overload**. *J Biomech.* 2016 Jul 5;49(10):2068-2075.

[228] Zimmerman WF, Miller MA, Cleary RJ, Izant TH, Mann KA.: **Damage in total knee replacements from mechanical overload**. *J Biomech.* 2016 Jul 5;49(10):2068-2075.

EXHIBIT 1

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FAX 866.470.6125

MARI SUSAN TRUMAN, M.S., P.E.

PROFESSIONAL EXPERIENCE

2002 to present **Mari S. Truman, OrthoBioMech LLC**
Principal Engineer/Manager
Orthopaedic device development offering design and development services for the orthopaedic and medical device industry. Recent projects include trauma, spine, hip and knee implant system design and development, risk assessments or other performance or stress analyses.

2005 to Present Provide technical investigations, analysis, reports, and testimony towards the resolution of commercial and personal injury litigation involving medical devices and/or biomechanical trauma and for failure analysis.

2002 to 2019 **Robson Forensic, Inc.**
Associate
Provide technical investigations, analysis, reports, and testimony towards the resolution of commercial and personal injury litigation involving medical devices and/or biomechanical trauma and for failure analysis.

2005 **Small Bone Innovations, Inc., (SBi)**
Senior Product Development Engineer
Principal engineer for upper and lower extremity trauma product systems.

2002 to 2003 **GE Medical Systems Navigation and Visualization, Inc.**
Mechanical Engineer, Orthopaedic Applications
Design and development of mechanical tools to facilitate image guided, minimally invasive orthopaedic surgical procedures.

1999 to 2002 **Seabrook International, LLC (DBA G&G Machine Technologies, LLC) and Nelson & Small Manufacturing Management**
Vice President of Product Development / Director, Midwest Region

- Founder and director of Seabrook's mid-west based design center offering design and development services for the orthopaedic and medical device industry.
- Providing general project management, design, and Design Dossier services for several new orthopaedic product systems for multiple orthopaedic companies. Recent product development projects include: Acetabular cups, knee implants and instruments, intramedullary nail implants and instruments, spinal implants and instruments, tools for less invasive surgical procedures, soft tissue attachment and a sternotomy repair system.

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- Implemented and use of multiple CAD/CAE software and communication tools including Unigraphics, Pro/E, Algor, SDRC IDEAS Artisan, and Solid Works.
- Medical device technical sales support for Seabrook International, LLC.
- Invention, invention refinement and patent application on new designs in conjunction with customers.

1998 to 1999 **Othy Inc, a division of Symmetry Medical Inc.**
Design Engineer

- Created custom and standard-line generic instrumentation for primary total knee, total hip, and endoscopic procedures, including a few unique/patentable inventions.
- Implemented company-wide participation in ISO 9001 level, team-oriented product development practices.
- Drafted and implemented "Fast Track" Design Control forms and protocols, to bring R&D practices into compliance with ISO & FDA regulations while making efficient use of existing R&D resources.
- Created engineering databases and spreadsheet programs for traditional closed form stress analyses.

1993 to 1998 **ArthroMotion LLC**
President and Founder

- Provided product design, development, and engineering services in orthopaedics.
- Completed several turnkey system development projects from inception through launch, in compliance with ISO & FDA design control regulations.
- Co-authored papers and talks with surgeons/researchers/engineering associates.
- Participated in collaborative research projects with several major biomechanics laboratories and orthopaedic teaching institutions.
- Named as an inventor on three Orthopaedic product device patents. Invented several other unique devices/concepts, which were patentable.
- Assisted with 8 patent applications, awarded three patents.

1991 to 1993 **Zimmer, a division of Bristol-Myers Squibb Company**
Senior Development Engineer, Fracture Management Division

- Completed unique fracture fixation biomechanical analyses and initiated cutting tool efficiency analyses.
- Assisted in the redesign and launch of the Herbert/Whipple Bone Screw System. Facilitated design and launch of the Herbert Mini Bone screws and the Herbert cannulated bone screw systems.
- Functioned as both project designer and project manager for these systems. Completed all design assurance documentation.
- Helped sales training department develop effective educational tools for the Herbert family products.

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1991 **Biomet Inc.**

Senior Engineer, Patient Matched Implants (PMI)

- Worked on methods to automate the production of implants utilizing 3D CT scan reconstructions.
- Supervision of radiology technologist whose duties ranged from completing 3D CT Scan reconstructions, writing field communications, giving tours, definition of CT scan parameters, and QC evaluation of composite plastic materials via CT scans.
- Design of custom prostheses and instruments to match patient and surgeon needs via CT scans or x-rays.
- Wrote and edited drafts of the surgical technique for patient matched hip implants (written and videotaped version).
- Conceptualized a unique, low cost, flexible sterilization case system.
- Designed a modular custom reamer and gage system.

1980 to 1991 **DePuy, a division of Boehringer Mannheim Corporation**

Sr. Product Development Engineer: 1989-1991

(Total Knee Implants and Instrumentation)

- Planned and started development of a new total knee implant and instrumentation system.
- Wrote surgical techniques, design rationales, and design assurance plans.
- Led project teams and coordinated research, planning, testing, design & development programs. Completed projects: AMK all-poly tibial tray, AMK Universal Femoral components, Tibial IM Alignment Guide.
- Planned educational sessions and spoke at sales training sessions both in-house and at national sales meetings.
- Frequently spoke to surgeon tour groups covering various contemporary orthopaedic topics.

Manager of Implant Technology – Hips & Knees: 1988-1989

LCS Knee System Marketing Product Manager

- Produced technical write-ups on topics such as Titanium, Titanium wear, Poly Wear, Competitive analyses of TKA systems, and TKA instrumentation.
- Re-wrote and updated LCS knee surgical technique, wall chart, planned LCS knee system modernization, line extension possibilities, held surgeon user focus meeting, ran LCS knee sales training meetings, and helped run dinner meetings (mini-courses).
- Created strategic planning documents for TKA, extremity and hip systems.
- Ran LCS knee sales training sessions, presented patellar kinematics and patello-femoral kinematics & competitive overview at DePuy's National Sales Meetings.

Marketing Product Manager Reconstructive II: 1986-1988

Total Knees & Extremity Joints

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- Planned and executed the launch of DePuy's AMK TKA systems.
- Responsible for the marketing/sales results for the total knee and extremity joint products, with emphasis on new product development and promotion.
- Coordinated creation of sales promotional programs, sales aids (audiovisual aids, advertisements, brochures, surgical techniques, design rationales, reference literature), and new product launch plans.
- Ran mini bioskills courses for surgeons, aided customer service, supplied financial justification of projects, submitted long and short-term product line plans and budget proposals.

Manager, New Product Coordination: 1985-1986

- Reduced lead-time and improved efficiency for new product development, production and introduction.
- Creation of refined new product development protocol, project timelines, project teams. Also responsible for new product production, “trouble-shooting.”

Development Engineer, Product Development Engineer: 1980-1985

- Responsibilities included product design, project management, and product line maintenance for multiple trauma, spine and extremity joint product areas.

EDUCATION

Biomedical Engineering; B.S.E. - The Catholic University of America, Washington D.C., 1980, Magna Cum Laude.

Course Highlights: Core curriculum met requirements for M.E. & Pre-Med majors. Including drafting, mechanical design, materials, 6 semesters physics, 8 semesters math, 8 semesters chemistry, computer science, biomedical design, and biomedical instrumentation.

M.S., Mechanical Engineering, University of Illinois, Urbana-Champaign, 2012.

Graduate Courses:

University of Toledo (UT): (1) Management of Projects & Technology Innovation; (2) Applications of Engineering Analysis

University of Illinois at Chicago (UIC): (1) Numerical Methods in Mechanical Engineering; (2) Dynamic Systems Analysis I; (3) Spine Biomechanics.

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University of Illinois at Urbana-Champaign: (1) Probability Theory I; (2) Legal Issues in Entrepreneurship; (4) Lectures in Entrepreneurship; (5) Introduction to Finite Element Analysis; (5) Quality Engineering, Six Sigma;(6) Decision Making with Multiattribute Utility Analysis; (7) Failure Analysis of Mechanical Components; (8) Technology Innovation and Strategy; (9) Managing Advanced Technology in Industry; (10) Fracture Resistant Design; (11) Corrosion of Metals.

Continuing Education:

Annually attended a minimum of 4 continuing education courses for orthopaedic surgeons between 1980 and 1990. Many since. A partial list of orthopaedic related continuing education courses attended:

Complex Case Controversies in Primary and Revision Total Knee Arthroplasty
Revision Total Hip Arthroplasty: How to Plan and How to Remove Components
Injuries of the Distal Radioulnar Joint
Spondylolysis and Spondylolisthesis
Arthroscopic Meniscal Repair
Tibial Nonunions: Current Treatment Concepts
Wrist Arthroscopy
Stable Internal Fixation for Fractures: Upper Extremity
Thoracolumbar Fractures
Deformity Correction Using External and Internal Fixation
Shoulder Arthroplasty: Current Techniques
Operative Management of Rotator Cuff Tears
Intramedullary Nailing of Upper Extremity Fractures
Physiology of Bone… Formation, Regeneration & Repair
Wrist Instabilities
External Fixation of High Energy Distal Tibial Fractures
Controversies in the Management of Open Fractures
Intramedullary Nailing of the Femur
Cervical Spine Trauma
Intra-Articular Fractures of the Distal Radius and Ulna
Management of Phalangeal and Metacarpal Fractures
Primary Total Hip Arthroplasty
Primary Total Knee Arthroplasty
Upper Extremity Injuries in the Young Athlete
Lumbar Spine: The Herniated Disc
Current Concepts in Joint Replacement

Put together course agendas for DePuy sponsored Total Knee Arthroplasty (TKA) orthopaedic surgeon continuing education meetings in 1987, 1988, and part of 1989. Attended AAOS meetings annually from 1981 to 2002.

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CosmosWorks Professional FEA
Pro/E Parametric Design/Modeling
SDRC IDEAS Parametric Design/Modeling & FEM/FEA **Training**
Introduction to FEM/FEA using Algor Software (1996, at Algor)
GMP Regulations
ISO 9000/9001/European Community (EC) Essential Requirements Regulation Status
Total Quality Management
IV-Tech Course on Machining (1982-83)
University of Wisconsin course Designing for Manufacturability (1981)
Dale Carnegie Course (1980)

I attend one or more injury biomechanics seminars and one or more orthopaedic research technical symposiums annually. My training specific to MVC injures includes:

- Annually participate in the OSU Injury biomechanics seminar and related continuing education courses in injury biomechanics research and related anatomy;
- Attend STAPP crash conference and SAE Safety research conferences;
  - Obtain and read safety research proceedings from STAPP, SAE and other crash programs such as ARCA
- Trained by Denton on crash dummies (types, history , use of);
- Spine biomechanics course, included injury biomechanics;
- Frequently search for and read peer review literatures related to injury biomechanics and CIREN crash research article ;
- Visited TRC to watch crash testing in process;
- Apply injury biomechanical research to case analyses on a daily basis;
- Completed drop impact testing using force plates, pressure sensitive fugi film;
  - Head neck model
  - Manikin (of 50% human male model)
  - Thoracic functional spinal units (cadaver tissue)
  - Dog and human functional spinal units

PROFESSIONAL REGISTRATIONS

Professional Engineer: Ohio

PROFESSIONAL MEMBERSHIPS and RECOGNITION

Member, Ohio Society of Professional Engineers (OSPE)
Member, National Society of Professional Engineers (NSPE)
Member, American Society of Mechanical Engineers (ASME)
Member, American Materials Society (AMS)
Member, American Society Testing and Materials International (ASTM)

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Member, International Society of Biomechanics (ISB)
Member, American Society of Biomechanics (ASB)
Member, American College of Sports Medicine (ACSM)
Associate Membership, Association for the Advancement of Automotive Medicine (AAAM)
Member, North American Spine Society (NASS)
Member, Society of Automotive Engineers (SAE)
Associate Member, Orthopedic Research Society (ORS)

Elected to Tau Beta Pi Engineering Honor Society, 1979
Sterling Who's Who Executive Edition, 1994/95
Mechanical Engineering Dept., C.C. Chang Award, Biomedical Engineering, 1980

PATENTS

5935128	Orthopaedic template system including a joint locator
5853413	Wrist fusion plate
5549690	Prosthetic thumb joint and method of manufacture
8025663	Augments for surgical instruments
8652183	Multi-angle orthopaedic expansion head fastener
8715325	Bone joining apparatus and method
8795333	Method and apparatus for repairing a tendon or ligament
8808387	Prosthetic joint *(knee patent*)
9072562	Bone joining device, kit and method
9468465	Reversible bone coupling device and method
9615873B2	Bone joining apparatus and method
9687286	Bone joining apparatus and method
10,357,299	Bone joining apparatus and method
10,639,083	Reversible bone coupling device and method

REFEREED PUBLISHED ABSTRACTS AND CONFERENCE PRESENTATIONS

1. Bodell, L., Hollister, A., Truman, M. and Focht, L.: **A New Implant and Procedure for Thumb Based Carpometacarpal Joint Reconstruction.** Presented at the 6th Congress of the International Federation of the Societies of for Surgery of the Hand, Helsinki, Finland, July 3-7, 1995.
2. Hollister, A., Truman, M. and Focht, L.: Creation **of a Thumb Carpometacarpal Joint Implant Saddle Shape with Surfaces of Revolution for Offset Axes of Rotation.** Presented at the 6th Congress of the International Federation of the Societies for Surgery of the Hand, Helsinki, Finland, July 3-7, 1995.
3. Hollister, A., Truman, M., and Focht, L.: **Computer Model of the Knee with Two Fixed Offset Revolutes for Tibiofemoral Motion.** Presented at the XVth Congress of the International Society of Biomechanics, Jyvaskyla, Finland, July 2-6, 1995.
4. Hollister, A., Truman, M., and Focht. L: **Computer Aided Design Model of the Knee with Two Fixed Offset Axes.** Abstracts - 14th Annual Meeting of the Arthroscopy Association of America, San Francisco, CA, May 4-7, 1995.

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5. Truman, M., Hollister, A., and Focht, L.: **Thumb Carpometacarpal Surface Replacement Arthroplasty with an Asymmetric Saddle**. Poster - American Society for Surgery of the Hand, 49th Meeting, Cincinnati, OH., October 26-29, 1994.
6. Truman, M., Hollister, A., and Focht, L.: **Prosthetic Joint Replacement Using Surfaces of Revolution for Two Offset Axes of Rotation**. Abstract ME '94 - International Congress - ASME Winter Annual Meeting, Chicago, IL., November 11, 1994.
7. Truman, M., Hollister, A., and Focht, L.: **Prosthetic Joint Replacement Design Methods to Restore Kinematics and Stability while Preventing Material Overload**. Proceedings - 14th Southern Biomedical Engineering Conference, Shreveport, LA, April 7-9, 1995.
8. Truman, M, and Hollister, A.: **Simulation of Thumb Carpometacarpal Joint Saddle Shape with Surfaces of Revolution for Offset Axes of Rotation**. Talk and **Computer Demonstration** Presented at the Vth Symposium on Computer Simulation in Biomechanics, Jyvaskyla, Finland, June 28-30, 1995.
9. Truman, M, and Hollister, A. **Mathematical Modeling of Joint Surface Shapes Using Surfaces of Revolution About Offset Revolutes.** Presented at Vth Symposium on Computer Simulation in Biomechanics, Jyvaskyla, Finland, June 28-30, 1995.
10. Truman, M, Hollister, A., and Focht, L.: **Simulation of Thumb Carpometacarpal Joint Saddle Shape with Surfaces of Revolution for Offset Axes of Rotation.** Presented at the XVth Congress of the International Society of Biomechanics, Jyvaskyla, Finland, July 2-6, 1995.
11. Truman, M, Hollister, A., and Focht, L.: **Simulation of Thumb Carpometacarpal Joint Saddle Shape with Surfaces of Revolution for Offset Axes of Rotation.** Presented at the International Hand and Wrist Biomechanics Symposium, September 10-11, 1995, San Francisco, CA.
12. Truman, M, and Hollister, A: **Simulated Articular Surface Shapes for the Thumb Carpometacarpal Joint.** Presented at the ASME Winter Annual Meeting, San Francisco, CA, November 12-17, 1995.
13. Griffin, A, and Truman, M: **Interfacing Between Rapid Prototyping and CAD,** Presented at the National Manufacturing Week Conference, the McCormick Center, Chicago IL, March 17 , 1998.
14. Truman, M.: **Implementation of Effective Design Control Procedures by Development Teams – tips based on historical experiences**, Presented at the Indiana Medical Device Manufacturer's Council (IMDMC) Seminar : Simplification of Process for Design Control: Medical Devices and Software, Indianapolis, IN April, 29, 1998.
15. Truman, M.: **Avoiding Patient Injury Lawsuits, Design Team Tips** BoneZone, Winter 2003 Knowledge Enterprises, Inc, Chagrin Falls, OH.
17. Ferrara, L., Moderator, Shuvo, R and Truman, M, Speakers: **Biomaterials and Future Engineering Considerations: What Do We Really Need?,** proceedings, North American Spine Society (NASS) Spring Break, Boca Raton, FL, April 23, 2004.
18. Truman, M., Ferrara, L., Milks, R., and Eckhardt, J.: **Acute Thoracic Vertebral Injury Thresholds.** Proceedings of IMECE04 2004 ASME International Mechanical Engineering Congress November 13–20, 2004, Anaheim, California USA.
19. Truman, M., Ferrara, L., Hunt, J., and Ganey, T.: **Mechanical transduction in a Truss Lumbar Fusion Cage: FEA results Match Mechanically Responsive Metrics of Bone Formation.** Proceedings, International Society for the Advancement of Spine Surgery (ISASS), Miami Beach, FL, USA, May 2, 2014.
20. Ngai V, Truman M, Williams J, Medley J: **Forensic Application of Biotribology**, *4th International Conference on Biotribology,* Montreal, Canada, September 26-29, 2018.

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LECTURES

1. Derian, G, and Truman, M. : Vehicle Collisions, Reconstruction and Injury Biomechanics, Lorman Continuing Legal Education Series, Columbus Ohio, January 26, 2005 & Cleveland Ohio, May 18, 2005.
2. Truman, M.:Use of Biomechanics to Explain Injury Mechanics and Reconstruct Events, *proceedings*, Presented at Forensics for Lawyers, OSBA CLE, Cleveland and Columbus OH, December 2002 & October 2003.
3. *Several other talks* for the Ohio State Bar Association (OSBA) and Ohio Trial Lawyer (OATL) Continuing Legal Education courses in 2003 and 2004 related to Injury Biomechanics and other Biomechanics Issues in Forensic Reconstructions.
4. Truman, M. : Preparing and Trying the Soft Tissue Case - Biomechanics Expert Reviews, Pennsylvania Bar Institute, Mechanicsburg, PA, July 20, 2006.
5. Truman, M.: Successful Resolution of Medical Equipment and Medical Malpractice Claims, Third Annual Medical Malpractice Insurance Execusummit, New York, NY, November 15, 2007.
6. Truman, M and Higinbotham, E.: Rebutting Seatbelt Defense and Preparing and Trying the Soft Tissue Case. Central Ohio Association for Justice (COAJ), Buckeye Hall of Fame Café, Columbus, OH, March 10, 2009.
7. Truman, M.: Evidence Pitfalls, Injury Biomechanics & Medical Devices, Columbus Bar Association, Columbus, OH, June 27, 2012.
8. Truman, M.: Soft Tissue Injuries in Low Speed Motor Vehicle Collisions, Lorman Continuing Legal Education Series Webcast, April 29, 2013. (Also a recorded version in September 2018)
9. Truman, M., and Martin, Lee, Litigating Slip, Trip and Fall Cases in Ohio Accident Reconstruction & Biomechanical Toolkit For Attorneys, AIA CES Course, Cincinnati, OH, December 18, 2015.

BIOMECHANICS AND INJURY EVENT RECONSTRUCTION

The physical principles and methods used in orthopaedic biomechanics are the same as those used to reconstruct injury events. Orthopaedic Biomechanics is a sub-specialty field of biomechanics and biomedical engineering and involves the application of principles of engineering mechanics to understand basic biological processes and mechanisms related to the structure and function of bone and other skeletal tissues, while the broader biomechanics field does the same relative to the structure and function of all living tissues.

Orthopaedic designers compile and use property databases of bone and other tissues. As a result, I routinely deal with forces that are applied to the human body during many activities, including impact and injury scenarios. To assure the safety and efficacy of new medical devices, we define clinically relevant performance requirements for their installation and use, and then test to define the product specific performance characteristics.

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- Comparison of event forces to injury thresholds

- Motions and forces applied by and to the skeleton/body during physiologic and injury events:
  1. Fall and fall recovery (stumbling)
  2. Projectile impacts
  3. Vehicular collisions
  4. Sports, recreation and occupational overuse or injury

sitting	standing	reclining
walking	jumping	running
climbing	jerking	throwing
lifting	pulling	pushing
biking	hiking	repetitive motion
vibration	bending	helmet impacts

  5. Altered/compensatory mechanics due to injury
  6. Physiologic event reaction times

- 36+ years of product design and development experience, orthopaedic medical devices

- Human joint reconstruction (since 1980)
  Implant Examples: Wrist, Ankle, Elbow, Knee, Fingers/Hand, Toes/Foot, Hip, Shoulder, Spine repair

- Skeletal trauma reconstruction (since 1980)
  Devices for: Long bones, juxta-articular (near joints), hand, vertebral (spine), sternum, face and skull.
  Implant Examples: Plates, screws, intramedullary nails, external fixation, pins, wires, staples, cables, clamps, anchors, distraction rods

- Tissue reattachment (since 1991)
  Implant Examples: Tissue Anchors used for ligament or tendon reattachment - knee, shoulder, wrist, ankle, hand and foot.

- Directed, analyzed and/or completed laboratory evaluations:
  1. Forces on/through normal vs. repaired bones and joints.
  2. In-vivo to in-vitro forces on orthopaedic implants.
  3. Normal (physiologic) vs. injury forces for skeletal tissues.
  4. Bone impact resistance, healthy vs. disease-weakened tissues.
  5. Bone cutting efficiency for specific orthopaedic surgical cutting tools.
  6. Documentation of altered gait, joint kinematics or mechanics after injury or orthopaedic repair or reconstruction considering modified injury potential and life style. Quantification of short or long-term functional disability.
  7. Range of motion, fatigue and wear endurance characterization of various total joint implant designs for the knee, hip, and wrist, PIP, thumb based CMC joint, and foot MT and DIP joints.

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8. Stability characteristics of joint implant devices and surgical reconstructions, including stability under anticipated physiologic and injury load conditions.
9. Impact strength and fracture resistance of bone, implants and instruments during surgical reconstruction procedures.
10. Implant fixation strength and construct stability characterization for various bone fracture repairs using: external fixation, spinal rods screws and hooks, intramedullary nails, bone screws, cannulated bone screws, plates with screws, and k-wires.
11. Ligament reattachment strength and fixation stability in foam bone model material and animal bone.
12. Minimally invasive orthopaedic surgical procedure instrument construct stability and accuracy.

MEDICAL DEVICES

- Determination of failure mechanisms, cause of failure.
- Review for device design, manufacturing or warning defects.
- Failure event reconstruction.
- Review of design dossiers and design history files including specifications, clinical performance requirements, test protocols, test results.
- Assist orthopaedic and medical device companies with design, design dossiers, test protocol development, test direction, and test results summary.

EXHIBIT 2

Mari S. Truman MS PE
History of Expert Testimony by Deposition or Trial

Date	Case Name & Description
2/12/2019	Muriel and Mark Van Horn vs Chubb Insurance company, United States Optimist Dinghy Association Inc., Alan Rubin and Progressive Insurance. In Civil Action File No. 2:17-12969 *United States District Court Eastern Division of Louisiana, New Orleans Louisiana* ; Deposition
6/4/2019	Dale Burningham and Lana Burningham vs Wright Medical Technology, Inc., and Wright Medical Group, Inc. In Case No. 2:17-cv-00092-JNP *United States District Court for the District of Utah, Central Division, Salt Lake City Utah*; Deposition
7/17/2019	John Bower, Plaintiff v. Wright Medical Technology, Inc., a Delaware corporation; and Microport Orthopedics, Inc., a Delaware corporation, Defendants. In Case No. 2:17-cv-03178-CAS (KSx) Catherine Prater, Plaintiff v. Wright Medical Technology, Inc., a Delaware corporation; and Microport Orthopedics, Inc., a Delaware corporation, Defendants. In Case No. 2:17-cv-03196- CAS (KSx) *United States District Court Central District of California, Los Angeles, CA* Deposition
9/11/2019	Hannah Payton v. Catlin Indemnity Company In Civil Action No. 16-CI-00340 *Commonwealth of Kentucky, Bullitt Circuit Court, Shepherdsville, KY* Deposition
12/3/2019	John Bower, Plaintiff v. Wright Medical Technology, Inc., a Delaware corporation; and Microport Orthopedics, Inc., a Delaware corporation, Defendants. In Case No. 2:17-cv-03178-CAS (KSx) Catherine Prater, Plaintiff v. Wright Medical Technology, Inc., a Delaware corporation; and Microport Orthopedics, Inc., a Delaware corporation, Defendants. In Case No. 2:17-cv-03196- CAS (KSx) *United States District Court Central District of California, Los Angeles, CA* Deposition
12/20/2019	Mathew Parker , Plaintiff, v Bombadier Recreational Products, Inc. a foreign corporation and BRP Inc., a foreign corporation, Defendants In Case No. 5:17-cv-11399 *United States District Court Central District of Michigan, Southern Division, Detroit MI* Deposition
12/30/2019	Michael A. Fiscaro and Deanna Fiscaro, H/W, Individually and as P.N.G. of Dominic Fiscaro, a Minor, Plaintiffs, v. Zoological Society of Philadelphia D/B/A Philadelphia Zoo and Vance Washington, Defendants

Mari S. Truman MS PE
History of Expert Testimony by Deposition or Trial

In April Term 2018, Case No. 5109
Court of Common Pleas Philadelphia County, Philadelphia, PA
Trial Deposition

1/3/2020 Demetrius D. Northern-Allison Plaintiff, vs John Seymour et al, Defendants
Case No. 18-CI-001963
Jefferson Circuit Court, Division Three (3), Louisville, KY
Trial Deposition

2/5/2020 Lynwood "Woody" Hardison Plaintiff, vs. Biomet, Defendant, in the Biomet M2a Magnum Hip Implant Products Liability Litigation (MDL2391)
Case No. 3:17-cv-00415-RLM-MGG
United States District Court, Northern District of Indiana, South Bend Division, South Bend, IN.
Deposition

4/22/2020 Mary K Hobbs, Plaintiff, -v - Dupont Crossing, LLC and The Salvation Army, Defendants
Civil Action Cause No. 02D09-1805-CT-000285
State of Indiana, In the Allen Superior Court, Ft. Wayne, Indiana; Deposition

5/20/2020 Mary Bayes, Plaintiff, vs. Biomet, Defendant, in the Biomet M2a Magnum Hip Implant Products Liability Litigation (MDL2391)
Civil Action Cause No.3:12-MD-2391-RLM-CAN
United States District Court, Northern District of Indiana, South Bend Division, South Bend, IN.
Deposition

6/25/2020 Randy Bohan, Plaintiff v. Wright Medical Technology, Inc., a Delaware corporation; Robert Lloyd Kurth, Douglas S. Hawkins, R&B Medical , Inc, and R&B Medical Services and Supplies Inc., Defendants.
In Case No. 18-C-218-3
In the Circuit Court of Harrison County, West Virginia, Clarksburg, WV
Deposition

7/28/2020 Mark Fitzsimmons, Plaintiff, vs. Biomet Inc., Biomet Orthopedics, LLC and Biomet Manufacturing Corp., Defendants
Civil Action Case No. 2:19-cv-182-FtM-29NPM
United States District Court, Middle District of Florida, Jacksonville, FL
Deposition

8/14/2020 Regina Dibala Plaintiff, v. DePuy Orthopaedics, Inc, an Indiana Corporation and Medical Device Business Services, Inc., an Indiana Corporation, Defendants
Civil Action No. 1:19-cv-1515-RBJ
United States District Court for the District of Colorado, Denver Colorado
Deposition

9/2/2020 Victor Kumalae and Michelle Avey, his wife, Plaintiffs, v. Robert Donnelly MD, Defendant

Mari S. Truman MS PE
History of Expert Testimony by Deposition or Trial

Uniform Case No.522014CA007383XXCICI, Reference No. 14-007383-CI-11
In the Circuit Court in and for Pinellas County, Clearwater, Florida
Deposition

9/25/2020 Smith & Nephew Birmingham Hip Resurfacing (BHR) Hip Implant Products Liability Litigation (BHR Track Cases)
Master Docket No. 1:17-md-2775
In the United States District Court, District of Maryland, Baltimore, Maryland;
Deposition

10/13/20 & 10/14/20 Mary Bayes, Plaintiff, vs. Biomet, Defendant, in the Biomet M2a Magnum Hip Implant Products Liability Litigation (MDL2391)
Civil Action Cause No.3:12-MD-2391-RLM-CAN;
United States District Court, Northern District of Indiana, South Bend Division, South Bend, IN.
Case No. 4:13-cv-00800-SRC
United States District Court, Eastern District of Missouri, Eastern Division, St Louis MO;
Trial

11/10/20 & 11/12/20 Lori Nicholson and William Willis Nicholson, Plaintiff, vs. Biomet, Defendant, in the Biomet M2a Magnum Hip Implant
Products Liability Litigation (MDL2391)
Civil Action Cause No.3:12-MD-2391-RLM-CAN
United States District Court, Northern District of Indiana, South Bend Division, South Bend, IN.
Case No. 18-CV-3057-CJWKEM
United States District Court, Northern District of Iowa, Cedar Rapids, IA;
Trial

11/18/20 Melissa O'Brien Plaintiff, v. Johnson & Johnson Medical Devices Companies; DePuy Synthes Companies, Does 1 to 10, Defendants.
Case No. 19-cv-00619-CJC-SP
United States District Court, Central District of California, Southern Division, Santa Ana, CA*;*
Deposition

11/23/20 Thomas Stillwagon and Linda Stillwagon, Plaintiffs, v. Exactech, Inc, a Florida Corporation; Exactech U.S. Inc a Florida Corporation; Defendants.
Case No. 2019-CA-001312
In the Circuit Court of the Eighth Judicial Circuit in an for Alachua County Florida, Gainesville, FL*;*
Deposition

12/04/20 David Dezelan and Annette Dezelan, Plaintiffs, v. Wayne Goldstein MD and Illinois Bone and Joint Institute, LLC; Defendants. Case No. 2017 L 1139
In the Circuit Court of Cook County Illinois, County Department, Law Division, Chicago , IL;
Deposition

EXHIBIT 2

Mari S. Truman MS PE
History of Expert Testimony by Deposition or Trial

12/11/20 Randal E. Dawson and Shirley Dawson, husband and wife, Plaintiffs, v. Zimmer, Inc. and Zimmer Biomet Holdings, Inc., f/k/a Zimmer Holdings, Inc., Defendants.
Case No. 2:19-cv-01544-MTL United States District Court, District of Arizona, Phoenix AZ;
Deposition

2/18/21 William W. Conway and Penny Conway, a married couple, Plaintiffs, v.Wright Medical Technology, Inc., a Delaware Corporation, Bio-Surge Solutions, Inc. an Arizona Corporation, Daniel Darges, Defendants.
Civil Action No. 4:18-cv-02095-SRC In the Superior Court in the State of Arizona in and for the County of Maricopa, Phoenix AZ;
Deposition

4/08/21 Zimmer M/L Taper Hip Prosthesis or M/L Taper Hip Prosthesis with Kinectiv Technology and Versys Femoral Head Products Liability Litigation, MDL No. 2859 18-MD-2859(PAC);18-MC-2859(PAC); United States District Court, Southern District of New York, New York, NY;
Deposition

4/16/21 Leslie Nazzaro, Plaintiff, v. Wright Medical Group, Inc., a Delaware corporation and Wright Medical Technology, Inc., a Delaware corporation , Defendants.
Case No. 2:18-cv-00368-RJS-DAO; United States District Court for the District of Utah, Central Division, Salt Lake City, Utah;
Deposition

5/05/21 Smith & Nephew Birmingham Hip Resurfacing (BHR) Hip Implant Products Liability Litigation (BHR Track Cases)
Master Docket No. 1:17-md-2775; *United States District Court, District of Maryland, Baltimore, Maryland;*
Cross Notice CT-002471-18m Division VII; *In the Circuit Court of Shelby County Tennessee for the Thirtieth Judicial District at Memphis*
Deposition

5/13/21 Randall and Liana Hix., Plaintiff, vs Zimmer Biomet Holdings, Inc. et al, Defendants; Biomet M2a Magnum Hip Implant Product Liability Litigation (MDL 2391)
Case No.: 3:18-cv-00437-RCJ-WGC
In the United States District Court, District of Nevada, Reno , Nevada;
Deposition

5/18/21 & 6/4/21 Charles E Newsom Plaintiff, v Wright Medical Technology, Inc., a Delaware Corporation et al, Defendants
Civil Action No. 3:19-cv-00196-DPM
United States District Court, for the Eastern District of Arkansas, Little Rock, Arkansas
Deposition

6/16/21 Bradley Dunlap and Jennifer Dunlap , a married couple, Plaintiffs ,v. Wright Medical technology Inc., a Delaware Corporation, Bio Alliance, Inc., an Arizona Corporation, et al.
Case No.: CV 2019-095233
In the Superior Court in the State of Arizona, the County of Maricopia, Phoenix , Arizona

Mari S. Truman MS PE
History of Expert Testimony by Deposition or Trial

Deposition

6/18/21 Angie B Collier, Plaintiff, v. Smith & Nephew, Inc. Defendant
Case No.: CT-003412-18, Division 4
In the Circuit Court of Shelby County, Tennessee for the Thirtieth Judicial District at Memphis, Memphis, Tennessee
Deposition

6/23/21 King D Hardy, Plaintiff, v. Wright Medical Technology, Inc., Defendant.
Case No.: CT-1721-19
In the Circuit Court of Shelby County, Tennessee for the Thirtieth Judicial District at Memphis, Memphis, Tennessee
Deposition

7/7/21 Lisa S. Schehrer, Plaintiff, v. Smith & Nephew, Inc. et al , Inc., Defendant.
Case No.: 18CV05904
In the Circuit Court of Johnson County, Kansas, Division 6,
Olathe, Kansas
Deposition

7/23/21 Pamela D Scott et al, Plaintiffs, vs Biomet, Inc. et al, Defendants; Biomet M2a Magnum Hip Implant Product Liability Litigation (MDL 2391)
Case No.: 2:15-cv-1180-RDP
In the United States District Court, Northern District of Alabama, Birmingham, Alabama;
Deposition

7/26/21 Kevin Carr, Plaintiff, vs. Monica Setchell and Pioneer Mutual Insurance Company, Defendants
Case No.: 18-004495-NI
State of Michigan, In the Circuit Court for the County of Macomb, Mount Clemens, Michigan;
Deposition

7/30/21 Paula P Redick and Jace D Redick v Smith & Nephew Birmingham Hip Resurfacing (BHR) Hip Implant Products Liability Litigation (BHR Track Cases)
Master Docket No. 1:17-md-2775; 1:17-cv-0094
In the United States District Court, District of Maryland, Baltimore, Maryland;
Trial

9/20/21 Jessica Williams, Plaintiff vs. University of Mississippi Medical Center, MIZUHO Orthopedic Systems, Inc., and John or Jane Does 1-10, Defendants
Civil Action No. 25C11: 18-cv-00285-JAW
In the Circuit Court of Hinds County, Jackson, Mississippi;
Deposition

9/27/21 John Bartis, Plaintiff(s), vs Biomet, Inc. et al, Defendants; Biomet M2a Magnum Hip Implant Product Liability Litigation (MDL 2391)
Case No.: 4:13-cv-00657-JAR
In the United States District Court, Eastern District of Missouri, St Louis, Missouri;

Mari S. Truman MS PE
History of Expert Testimony by Deposition or Trial

Deposition

9/29/21 Virginia Lehman Plaintiff, vs. Sandra K Nunn and USAA Casualty Insurance Company, Defendants
Civil Action Cause No. 20-CI-000782
Jefferson Circuit Court, Division Four (4), Louisville, Kentucky;
Deposition

11/18/21 Cynthia Boden, et al Plaintiffs, v. Biomet, Inc., et al. Defendants.
Biomet M2a Magnum Hip Implant Product Liability Litigation
Case No.: 4:21-CV-00145-SRC
In the United States District Court, Eastern District of Missouri, St Louis, Missouri;
Deposition

11/22/21 Susan J. McAleavey and Richard Bertoli, Plaintiffs, v. Wright Medical Technology, Inc., et al., Defendants.
Case No. 2:20-cv-01703-GMS
In the United States District Court, For the District of Arizona, Phoenix Division, Phoenix, Arizona;
Deposition

11/24/21 Genie Eiter, et al, Plaintiffs,v. Wright Medical Technology, Inc., Defendant.
Case No.: CV-20-00552-PHX-DJH
In the United States District Court, For the District of Arizona, Phoenix Division, Phoenix, Arizona;
Deposition

12/1/21 John Paul Gill and Lori Ann Gill, Plaintiff(s), vs Biomet Orthopedics, LLC, Biomet, Inc., Biomet Manufacturing, LLC, and Biomet U.S. Reconstruction, LLC, Defendants; Biomet M2a Magnum Hip Implant Product Liability Litigation (MDL 2391)
Case No.: CIV-19-267-D
In the United States District Court, For the Western District of Oklahoma, Oklahoma City, Oklahoma;
Deposition

01/06/22 Michael K Evans, Jr vs. Arthrex, Inc. and Midsouth Orthopedics, Inc.
Case No.: 19CV-2019-30
In the Circuit Court of Cross County, Arkansas, Civil Division, Wynne, Arkansas;
Deposition

02/11/22 Chase Kerns, Plaintiff, v. Concord Community Schools
Cause No.: 20D01-1911-CT-000239
In the State of Indiana, County of Elkhart, in the Elkhart Superior Court, Elkhart, Indiana;
Deposition

EXHIBIT 2

Mari S. Truman MS PE
History of Expert Testimony by Deposition or Trial

02/25/22 Lenore Daudlin individually, by her Guardian, Karne Gentner, Plaintiff, v. Zimmer Biomet, Inc. f/k/a Zimmer Inc., and Zimmer Biomet Holdings, Inc. f/k/a Zimmer Holdings, Inc., Defendants.
Case No.: 2:20-cv-12045-SFC-DRG
In the United States District Court, Eastern District of Michigan, Detroit, Michigan;
Deposition

03/01/22 Marla H. Hand and James T. Nyeste v. Smith & Nephew Birmingham Hip Resurfacing (BHR)
03/02/22 Deborah Quirk v. Smith & Nephew Birmingham Hip Resurfacing (BHR)
Hip Implant Products Liability Litigation (BHR Track Cases)
Master Docket No. 1:17-md-2775; No. 1:17-cv-00935 (Hand) & 1:18-cv-02328 (Quirk)
In the United States District Court, District of Maryland, Baltimore, Maryland;
Deposition

03/17/22 Chase Kerns, Plaintiff, v. Concord Community Schools
Cause No.: 20D01-1911-CT-000239
In the State of Indiana, County of Elkhart, in the Elkhart Superior Court, Elkhart, Indiana;
Trial

06/22/22 United States of America et al, *ex rel* Brooks Wallace, Robert Farley and Manual Fuentes, Plaintiffs, v. Exactech, Inc., Defendants.
Civil Action No. 2:18-CV-01010-LSC
In the United States District Court, Northern District of Alabama, Birmingham, Alabama;
Deposition

09/13/22 Tiffany Stone and Daniel Stone, Plaintiffs, v. Ana M. Hernandez, Defendant
Cause No.: 71C01-2010-CT-000397
In the State of Indiana, County of St. Joseph, in the St. Joseph Circuit Court, South Bend, Indiana;
Deposition

EXHIBIT 2

Mari S. Truman MS PE
History of Expert Testimony by Deposition or Trial

11/16/22	Plaintiff(s)	Case No
11/17/22	Michael Baldwin;	3:12-cv-00731-K
	Crystal Brown;	3:11-cv-02574-K
	Sherry Campbell;	3:11-cv-01959-K
	Brenda Getz;	3:11-cv-02890-K
	Linda Gulledge;	3:12-cv-03301-K
	Bennie W Holland Jr;	3:13-cv-02935-K
	Billy Nation;	3:12-cv-03369-K
	Charles O'Connell;	3:12-cv-01480-K
	Alicia Taffurelli, obo Kurt Taffurelli (deceased);	3:12-cv-003371-K
	and Warren Wright; Plaintiffs vs. DePuy Orthopaedics Inc., et al., Defendants	3:11-cv-02534-K

In RE DePuy Orthopaedics, Inc., Pinnacle Hip Implant Products Liability Litigation , MDL Master Docket No. 3:11-MD-2244-K, Judge Ed Kinkeade
In the United States District Court, Northern District of Texas, Dallas Division, Dallas, Texas; Deposition

12/20/22 Brittany Jacobs, an incapacitated person, by and through her mother and Plenary Guardian, Lynn Jacobs; and seven other Plaintiffs v. Clarence Beamer, Jr. , Werener Bus Lines, Inc. d/b/a Werner Coach FKW, Inc., Krystal Infinity, d/b/a Krystal Enterprises, Thor Inductries, Inc., REV Group, Inc., Navitstar, Inc. d/b/a International Trucks, Defendants.
Case No.: 181103180
In Philadelphia County Court of Common Pleas, Philadelphia, Pennsylvania;
Trial Deposition

01/10/23 Jacob Hobus, Plaintiff vs. Howmedical Osteonics Corp., a New Jersey Corporation, Defendant.
Civil Action No3:21-cv-00080-AC
United States District Court for the District of Oregon, Portland Division, Portland, Oregon; Deposition

01/30/23 Darlene Thompson, Plaintiff, vs Jenny's Farm Stand, Defendant.
Case No. 19-1188-NO
State of Michigan in the Circuit Court for the County of Washtenaw; Ann Arbor Michigan
Trial

02/21/23 Corinne Bennington, a Colorado resident, Plaintiff, v. Stryker Corporation, a Michigan corporation; Stryker Sales Corporation, a Michigan corporation; Howmedica Osteonics Corporation, a New Jersey corporation; and Doe Entities 11-20, inclusive, defendants.
Regina Dibala Plaintiff, v. DePuy Orthopaedics, Inc, an Indiana Corporation and Medical Device Business Services, Inc., an Indiana Corporation, Defendants
Civil Action No. 20-cv-01211-CMA-GPG
United States District Court for the District of Colorado, Denver Colorado
Deposition

EXHIBIT 2

PRODBEG	PRODEND	PRODBEGATT	PRODENDATT	CUSTODIAN	Production Volume
DEPATT_00127671	DEPATT_00127672	DEPATT_00127671	DEPATT_00127672	DHFs	DEPATT_PROD002
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DEPATT_00127675	DEPATT_00127677	DEPATT_00127675	DEPATT_00127677	DHFs	DEPATT_PROD002
DEPATT_00127678	DEPATT_00127755	DEPATT_00127678	DEPATT_00127755	DHFs	DEPATT_PROD002
DEPATT_00127756	DEPATT_00127777	DEPATT_00127756	DEPATT_00127777	DHFs	DEPATT_PROD002
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DEPATT_00130737	DEPATT_00130737	DEPATT_00130737	DEPATT_00130737	DHFs	DEPATT_PROD002

PRODBEG	PRODEND	PRODBEGATT	PRODENDATT	CUSTODIAN	Production Volume
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DEPATT_00130898	DEPATT_00130930	DEPATT_00130898	DEPATT_00130930	DHFs	DEPATT_PROD002
DEPATT_00130931	DEPATT_00130980	DEPATT_00130931	DEPATT_00130980	DHFs	DEPATT_PROD002
DEPATT_00130981	DEPATT_00130988	DEPATT_00130981	DEPATT_00130988	DHFs	DEPATT_PROD002
DEPATT_00130989	DEPATT_00131027	DEPATT_00130989	DEPATT_00131027	DHFs	DEPATT_PROD002
DEPATT_00131028	DEPATT_00131064	DEPATT_00131028	DEPATT_00131064	DHFs	DEPATT_PROD002
DEPATT_00131065	DEPATT_00131072	DEPATT_00131065	DEPATT_00131072	DHFs	DEPATT_PROD002
DEPATT_00131073	DEPATT_00131094	DEPATT_00131073	DEPATT_00131094	DHFs	DEPATT_PROD002
DEPATT_00131095	DEPATT_00131095	DEPATT_00131095	DEPATT_00131095	DHFs	DEPATT_PROD002
DEPATT_00131096	DEPATT_00131096	DEPATT_00131096	DEPATT_00131096	DHFs	DEPATT_PROD002
DEPATT_00131097	DEPATT_00131097	DEPATT_00131097	DEPATT_00131097	DHFs	DEPATT_PROD002
DEPATT_00131098	DEPATT_00131098	DEPATT_00131098	DEPATT_00131098	DHFs	DEPATT_PROD002
DEPATT_00131099	DEPATT_00131100	DEPATT_00131099	DEPATT_00131100	DHFs	DEPATT_PROD002
DEPATT_00131101	DEPATT_00131103	DEPATT_00131101	DEPATT_00131103	DHFs	DEPATT_PROD002
DEPATT_00131104	DEPATT_00131112	DEPATT_00131104	DEPATT_00131112	DHFs	DEPATT_PROD002
DEPATT_00131113	DEPATT_00131113	DEPATT_00131113	DEPATT_00131113	DHFs	DEPATT_PROD002
DEPATT_00131114	DEPATT_00131114	DEPATT_00131114	DEPATT_00131114	DHFs	DEPATT_PROD002
DEPATT_00131115	DEPATT_00131137	DEPATT_00131115	DEPATT_00131137	DHFs	DEPATT_PROD002
DEPATT_00131138	DEPATT_00131154	DEPATT_00131138	DEPATT_00131154	DHFs	DEPATT_PROD002
DEPATT_00131155	DEPATT_00131179	DEPATT_00131155	DEPATT_00131179	DHFs	DEPATT_PROD002
DEPATT_00131180	DEPATT_00131202	DEPATT_00131180	DEPATT_00131202	DHFs	DEPATT_PROD002
DEPATT_00131203	DEPATT_00131222	DEPATT_00131203	DEPATT_00131222	DHFs	DEPATT_PROD002
DEPATT_00131223	DEPATT_00131245	DEPATT_00131223	DEPATT_00131245	DHFs	DEPATT_PROD002
DEPATT_00131246	DEPATT_00131262	DEPATT_00131246	DEPATT_00131262	DHFs	DEPATT_PROD002
DEPATT_00131263	DEPATT_00131269	DEPATT_00131263	DEPATT_00131269	DHFs	DEPATT_PROD002
DEPATT_00131270	DEPATT_00131328	DEPATT_00131270	DEPATT_00131328	DHFs	DEPATT_PROD002
DEPATT_00131329	DEPATT_00131342	DEPATT_00131329	DEPATT_00131342	DHFs	DEPATT_PROD002
DEPATT_00131343	DEPATT_00131360	DEPATT_00131343	DEPATT_00131360	DHFs	DEPATT_PROD002
DEPATT_00131361	DEPATT_00131380	DEPATT_00131361	DEPATT_00131380	DHFs	DEPATT_PROD002
DEPATT_00131381	DEPATT_00131500	DEPATT_00131381	DEPATT_00131500	DHFs	DEPATT_PROD002
DEPATT_00131501	DEPATT_00131553	DEPATT_00131501	DEPATT_00131553	DHFs	DEPATT_PROD002
DEPATT_00131554	DEPATT_00131555	DEPATT_00131554	DEPATT_00131555	DHFs	DEPATT_PROD002
DEPATT_00131556	DEPATT_00131557	DEPATT_00131556	DEPATT_00131557	DHFs	DEPATT_PROD002
DEPATT_00131558	DEPATT_00131558	DEPATT_00131558	DEPATT_00131558	DHFs	DEPATT_PROD002
DEPATT_00131559	DEPATT_00131559	DEPATT_00131559	DEPATT_00131559	DHFs	DEPATT_PROD002
DEPATT_00131560	DEPATT_00131562	DEPATT_00131560	DEPATT_00131562	DHFs	DEPATT_PROD002
DEPATT_00131563	DEPATT_00131574	DEPATT_00131563	DEPATT_00131574	DHFs	DEPATT_PROD002
DEPATT_00131575	DEPATT_00131585	DEPATT_00131575	DEPATT_00131585	DHFs	DEPATT_PROD002
DEPATT_00131586	DEPATT_00131598	DEPATT_00131586	DEPATT_00131598	DHFs	DEPATT_PROD002
DEPATT_00131599	DEPATT_00131601	DEPATT_00131599	DEPATT_00131601	DHFs	DEPATT_PROD002
DEPATT_00131602	DEPATT_00131617	DEPATT_00131602	DEPATT_00131617	DHFs	DEPATT_PROD002
DEPATT_00131618	DEPATT_00131621	DEPATT_00131618	DEPATT_00131621	DHFs	DEPATT_PROD002
DEPATT_00131622	DEPATT_00131627	DEPATT_00131622	DEPATT_00131627	DHFs	DEPATT_PROD002
DEPATT_00131628	DEPATT_00131638	DEPATT_00131628	DEPATT_00131638	DHFs	DEPATT_PROD002
DEPATT_00131639	DEPATT_00131647	DEPATT_00131639	DEPATT_00131647	DHFs	DEPATT_PROD002
DEPATT_00131648	DEPATT_00131667	DEPATT_00131648	DEPATT_00131667	DHFs	DEPATT_PROD002
DEPATT_00131668	DEPATT_00131674	DEPATT_00131668	DEPATT_00131674	DHFs	DEPATT_PROD002
DEPATT_00131675	DEPATT_00131683	DEPATT_00131675	DEPATT_00131683	DHFs	DEPATT_PROD002
DEPATT_00131684	DEPATT_00131689	DEPATT_00131684	DEPATT_00131689	DHFs	DEPATT_PROD002
DEPATT_00131690	DEPATT_00131702	DEPATT_00131690	DEPATT_00131702	DHFs	DEPATT_PROD002
DEPATT_00131703	DEPATT_00131704	DEPATT_00131703	DEPATT_00131704	DHFs	DEPATT_PROD002

PRODBEG	PRODEND	PRODBEGATT	PRODENDATT	CUSTODIAN	Production Volume
DEPATT_00131705	DEPATT_00131707	DEPATT_00131705	DEPATT_00131707	DHFs	DEPATT_PROD002
DEPATT_00131708	DEPATT_00131716	DEPATT_00131708	DEPATT_00131716	DHFs	DEPATT_PROD002
DEPATT_00131717	DEPATT_00131732	DEPATT_00131717	DEPATT_00131732	DHFs	DEPATT_PROD002
DEPATT_00131733	DEPATT_00131795	DEPATT_00131733	DEPATT_00131795	DHFs	DEPATT_PROD002
DEPATT_00131796	DEPATT_00131799	DEPATT_00131796	DEPATT_00131799	DHFs	DEPATT_PROD002
DEPATT_00131800	DEPATT_00131802	DEPATT_00131800	DEPATT_00131802	DHFs	DEPATT_PROD002
DEPATT_00131803	DEPATT_00131808	DEPATT_00131803	DEPATT_00131808	DHFs	DEPATT_PROD002
DEPATT_00131809	DEPATT_00131813	DEPATT_00131809	DEPATT_00131813	DHFs	DEPATT_PROD002
DEPATT_00131814	DEPATT_00131824	DEPATT_00131814	DEPATT_00131824	DHFs	DEPATT_PROD002
DEPATT_00131825	DEPATT_00131835	DEPATT_00131825	DEPATT_00131835	DHFs	DEPATT_PROD002
DEPATT_00131836	DEPATT_00131844	DEPATT_00131836	DEPATT_00131844	DHFs	DEPATT_PROD002
DEPATT_00131845	DEPATT_00131863	DEPATT_00131845	DEPATT_00131863	DHFs	DEPATT_PROD002
DEPATT_00131864	DEPATT_00131883	DEPATT_00131864	DEPATT_00131883	DHFs	DEPATT_PROD002
DEPATT_00131884	DEPATT_00131887	DEPATT_00131884	DEPATT_00131887	DHFs	DEPATT_PROD002
DEPATT_00131888	DEPATT_00131894	DEPATT_00131888	DEPATT_00131894	DHFs	DEPATT_PROD002
DEPATT_00131895	DEPATT_00131897	DEPATT_00131895	DEPATT_00131897	DHFs	DEPATT_PROD002
DEPATT_00131898	DEPATT_00131906	DEPATT_00131898	DEPATT_00131906	DHFs	DEPATT_PROD002
DEPATT_00131907	DEPATT_00131910	DEPATT_00131907	DEPATT_00131910	DHFs	DEPATT_PROD002
DEPATT_00131911	DEPATT_00131913	DEPATT_00131911	DEPATT_00131913	DHFs	DEPATT_PROD002
DEPATT_00131914	DEPATT_00131917	DEPATT_00131914	DEPATT_00131917	DHFs	DEPATT_PROD002
DEPATT_00131918	DEPATT_00131929	DEPATT_00131918	DEPATT_00131929	DHFs	DEPATT_PROD002
DEPATT_00131930	DEPATT_00131933	DEPATT_00131930	DEPATT_00131933	DHFs	DEPATT_PROD002
DEPATT_00131934	DEPATT_00131944	DEPATT_00131934	DEPATT_00131944	DHFs	DEPATT_PROD002
DEPATT_00131945	DEPATT_00131945	DEPATT_00131945	DEPATT_00131945	DHFs	DEPATT_PROD002
DEPATT_00131946	DEPATT_00131948	DEPATT_00131946	DEPATT_00131948	DHFs	DEPATT_PROD002
DEPATT_00131949	DEPATT_00131950	DEPATT_00131949	DEPATT_00131950	DHFs	DEPATT_PROD002
DEPATT_00131951	DEPATT_00131955	DEPATT_00131951	DEPATT_00131955	DHFs	DEPATT_PROD002
DEPATT_00131956	DEPATT_00131956	DEPATT_00131956	DEPATT_00131956	DHFs	DEPATT_PROD002
DEPATT_00131957	DEPATT_00131958	DEPATT_00131957	DEPATT_00131958	DHFs	DEPATT_PROD002
DEPATT_00131959	DEPATT_00132075	DEPATT_00131959	DEPATT_00132075	DHFs	DEPATT_PROD002
DEPATT_00132076	DEPATT_00132078	DEPATT_00132076	DEPATT_00132078	DHFs	DEPATT_PROD002
DEPATT_00132079	DEPATT_00132084	DEPATT_00132079	DEPATT_00132084	DHFs	DEPATT_PROD002
DEPATT_00132085	DEPATT_00132088	DEPATT_00132085	DEPATT_00132088	DHFs	DEPATT_PROD002
DEPATT_00132089	DEPATT_00132097	DEPATT_00132089	DEPATT_00132097	DHFs	DEPATT_PROD002
DEPATT_00132098	DEPATT_00132100	DEPATT_00132098	DEPATT_00132100	DHFs	DEPATT_PROD002
DEPATT_00132101	DEPATT_00132106	DEPATT_00132101	DEPATT_00132106	DHFs	DEPATT_PROD002
DEPATT_00132107	DEPATT_00132111	DEPATT_00132107	DEPATT_00132111	DHFs	DEPATT_PROD002
DEPATT_00132112	DEPATT_00132113	DEPATT_00132112	DEPATT_00132113	DHFs	DEPATT_PROD002
DEPATT_00132114	DEPATT_00132116	DEPATT_00132114	DEPATT_00132116	DHFs	DEPATT_PROD002
DEPATT_00132117	DEPATT_00132118	DEPATT_00132117	DEPATT_00132118	DHFs	DEPATT_PROD002
DEPATT_00132119	DEPATT_00132120	DEPATT_00132119	DEPATT_00132120	DHFs	DEPATT_PROD002
DEPATT_00132121	DEPATT_00132141	DEPATT_00132121	DEPATT_00132141	DHFs	DEPATT_PROD002
DEPATT_00132142	DEPATT_00132143	DEPATT_00132142	DEPATT_00132143	DHFs	DEPATT_PROD002
DEPATT_00132144	DEPATT_00132188	DEPATT_00132144	DEPATT_00132188	DHFs	DEPATT_PROD002
DEPATT_00132189	DEPATT_00132195	DEPATT_00132189	DEPATT_00132195	DHFs	DEPATT_PROD002
DEPATT_00132196	DEPATT_00132199	DEPATT_00132196	DEPATT_00132199	DHFs	DEPATT_PROD002
DEPATT_00132200	DEPATT_00132223	DEPATT_00132200	DEPATT_00132223	DHFs	DEPATT_PROD002
DEPATT_00132224	DEPATT_00132237	DEPATT_00132224	DEPATT_00132237	DHFs	DEPATT_PROD002
DEPATT_00132238	DEPATT_00132244	DEPATT_00132238	DEPATT_00132244	DHFs	DEPATT_PROD002
DEPATT_00132245	DEPATT_00132249	DEPATT_00132245	DEPATT_00132249	DHFs	DEPATT_PROD002
DEPATT_00132250	DEPATT_00132260	DEPATT_00132250	DEPATT_00132260	DHFs	DEPATT_PROD002
DEPATT_00132261	DEPATT_00132277	DEPATT_00132261	DEPATT_00132277	DHFs	DEPATT_PROD002
DEPATT_00132278	DEPATT_00132288	DEPATT_00132278	DEPATT_00132288	DHFs	DEPATT_PROD002
DEPATT_00132289	DEPATT_00132305	DEPATT_00132289	DEPATT_00132305	DHFs	DEPATT_PROD002
DEPATT_00132306	DEPATT_00132317	DEPATT_00132306	DEPATT_00132317	DHFs	DEPATT_PROD002
DEPATT_00132318	DEPATT_00132328	DEPATT_00132318	DEPATT_00132328	DHFs	DEPATT_PROD002
DEPATT_00132329	DEPATT_00132333	DEPATT_00132329	DEPATT_00132333	DHFs	DEPATT_PROD002

PRODBEG	PRODEND	PRODBEGATT	PRODENDATT	CUSTODIAN	Production Volume
DEPATT_00132334	DEPATT_00132346	DEPATT_00132334	DEPATT_00132346	DHFs	DEPATT_PROD002
DEPATT_00132347	DEPATT_00132349	DEPATT_00132347	DEPATT_00132349	DHFs	DEPATT_PROD002
DEPATT_00132350	DEPATT_00132351	DEPATT_00132350	DEPATT_00132351	DHFs	DEPATT_PROD002
DEPATT_00132352	DEPATT_00132353	DEPATT_00132352	DEPATT_00132353	DHFs	DEPATT_PROD002
DEPATT_00132354	DEPATT_00132355	DEPATT_00132354	DEPATT_00132355	DHFs	DEPATT_PROD002
DEPATT_00132356	DEPATT_00132360	DEPATT_00132356	DEPATT_00132360	DHFs	DEPATT_PROD002
DEPATT_00132361	DEPATT_00132362	DEPATT_00132361	DEPATT_00132362	DHFs	DEPATT_PROD002
DEPATT_00132363	DEPATT_00132363	DEPATT_00132363	DEPATT_00132363	DHFs	DEPATT_PROD002
DEPATT_00132364	DEPATT_00132377	DEPATT_00132364	DEPATT_00132377	DHFs	DEPATT_PROD002
DEPATT_00132378	DEPATT_00132380	DEPATT_00132378	DEPATT_00132380	DHFs	DEPATT_PROD002
DEPATT_00132381	DEPATT_00132383	DEPATT_00132381	DEPATT_00132383	DHFs	DEPATT_PROD002
DEPATT_00132384	DEPATT_00132401	DEPATT_00132384	DEPATT_00132401	DHFs	DEPATT_PROD002
DEPATT_00132402	DEPATT_00132403	DEPATT_00132402	DEPATT_00132403	DHFs	DEPATT_PROD002
DEPATT_00132404	DEPATT_00132407	DEPATT_00132404	DEPATT_00132407	DHFs	DEPATT_PROD002
DEPATT_00132408	DEPATT_00132410	DEPATT_00132408	DEPATT_00132410	DHFs	DEPATT_PROD002
DEPATT_00132411	DEPATT_00132719	DEPATT_00132411	DEPATT_00132719	DHFs	DEPATT_PROD002
DEPATT_00132720	DEPATT_00132965	DEPATT_00132720	DEPATT_00132965	DHFs	DEPATT_PROD002
DEPATT_00132966	DEPATT_00133362	DEPATT_00132966	DEPATT_00133362	DHFs	DEPATT_PROD002
DEPATT_00133363	DEPATT_00133377	DEPATT_00133363	DEPATT_00133377	DHFs	DEPATT_PROD002
DEPATT_00133378	DEPATT_00133398	DEPATT_00133378	DEPATT_00133398	DHFs	DEPATT_PROD002
DEPATT_00133399	DEPATT_00133420	DEPATT_00133399	DEPATT_00133420	DHFs	DEPATT_PROD002
DEPATT_00133421	DEPATT_00133585	DEPATT_00133421	DEPATT_00133585	DHFs	DEPATT_PROD002
DEPATT_00133586	DEPATT_00133608	DEPATT_00133586	DEPATT_00133608	DHFs	DEPATT_PROD002
DEPATT_00133609	DEPATT_00133610	DEPATT_00133609	DEPATT_00133610	DHFs	DEPATT_PROD002
DEPATT_00133611	DEPATT_00133613	DEPATT_00133611	DEPATT_00133613	DHFs	DEPATT_PROD002
DEPATT_00133614	DEPATT_00133627	DEPATT_00133614	DEPATT_00133627	DHFs	DEPATT_PROD002
DEPATT_00133628	DEPATT_00133645	DEPATT_00133628	DEPATT_00133645	DHFs	DEPATT_PROD002
DEPATT_00133646	DEPATT_00133647	DEPATT_00133646	DEPATT_00133647	DHFs	DEPATT_PROD002
DEPATT_00133648	DEPATT_00133666	DEPATT_00133648	DEPATT_00133666	DHFs	DEPATT_PROD002
DEPATT_00133667	DEPATT_00133677	DEPATT_00133667	DEPATT_00133677	DHFs	DEPATT_PROD002
DEPATT_00133678	DEPATT_00133689	DEPATT_00133678	DEPATT_00133689	DHFs	DEPATT_PROD002
DEPATT_00133690	DEPATT_00133695	DEPATT_00133690	DEPATT_00133695	DHFs	DEPATT_PROD002
DEPATT_00133696	DEPATT_00133710	DEPATT_00133696	DEPATT_00133710	DHFs	DEPATT_PROD002
DEPATT_00133711	DEPATT_00133724	DEPATT_00133711	DEPATT_00133724	DHFs	DEPATT_PROD002
DEPATT_00133725	DEPATT_00133726	DEPATT_00133725	DEPATT_00133726	DHFs	DEPATT_PROD002
DEPATT_00133727	DEPATT_00133727	DEPATT_00133727	DEPATT_00133727	DHFs	DEPATT_PROD002
DEPATT_00133728	DEPATT_00133728	DEPATT_00133728	DEPATT_00133728	DHFs	DEPATT_PROD002
DEPATT_00133729	DEPATT_00133739	DEPATT_00133729	DEPATT_00133739	DHFs	DEPATT_PROD002
DEPATT_00133740	DEPATT_00133753	DEPATT_00133740	DEPATT_00133753	DHFs	DEPATT_PROD002
DEPATT_00133754	DEPATT_00133755	DEPATT_00133754	DEPATT_00133755	DHFs	DEPATT_PROD002
DEPATT_00133756	DEPATT_00133782	DEPATT_00133756	DEPATT_00133782	DHFs	DEPATT_PROD002
DEPATT_00133783	DEPATT_00133784	DEPATT_00133783	DEPATT_00133784	DHFs	DEPATT_PROD002
DEPATT_00133785	DEPATT_00133817	DEPATT_00133785	DEPATT_00133817	DHFs	DEPATT_PROD002
DEPATT_00133818	DEPATT_00133833	DEPATT_00133818	DEPATT_00133833	DHFs	DEPATT_PROD002
DEPATT_00133834	DEPATT_00133844	DEPATT_00133834	DEPATT_00133844	DHFs	DEPATT_PROD002
DEPATT_00133845	DEPATT_00133846	DEPATT_00133845	DEPATT_00133846	DHFs	DEPATT_PROD002
DEPATT_00133847	DEPATT_00133848	DEPATT_00133847	DEPATT_00133848	DHFs	DEPATT_PROD002
DEPATT_00133849	DEPATT_00133850	DEPATT_00133849	DEPATT_00133850	DHFs	DEPATT_PROD002
DEPATT_00133851	DEPATT_00133852	DEPATT_00133851	DEPATT_00133852	DHFs	DEPATT_PROD002
DEPATT_00133853	DEPATT_00133855	DEPATT_00133853	DEPATT_00133855	DHFs	DEPATT_PROD002
DEPATT_00133856	DEPATT_00133858	DEPATT_00133856	DEPATT_00133858	DHFs	DEPATT_PROD002
DEPATT_00133859	DEPATT_00133859	DEPATT_00133859	DEPATT_00133859	DHFs	DEPATT_PROD002
DEPATT_00133860	DEPATT_00133860	DEPATT_00133860	DEPATT_00133860	DHFs	DEPATT_PROD002
DEPATT_00133861	DEPATT_00133861	DEPATT_00133861	DEPATT_00133861	DHFs	DEPATT_PROD002
DEPATT_00133862	DEPATT_00133862	DEPATT_00133862	DEPATT_00133862	DHFs	DEPATT_PROD002
DEPATT_00133863	DEPATT_00133863	DEPATT_00133863	DEPATT_00133863	DHFs	DEPATT_PROD002
DEPATT_00133864	DEPATT_00133864	DEPATT_00133864	DEPATT_00133864	DHFs	DEPATT_PROD002

PRODBEG	PRODEND	PRODBEGATT	PRODENDATT	CUSTODIAN	Production Volume
DEPATT_00133865	DEPATT_00133870	DEPATT_00133865	DEPATT_00133870	DHFs	DEPATT_PROD002
DEPATT_00133871	DEPATT_00133871	DEPATT_00133871	DEPATT_00133871	DHFs	DEPATT_PROD002
DEPATT_00133872	DEPATT_00133893	DEPATT_00133872	DEPATT_00133893	DHFs	DEPATT_PROD002
DEPATT_00133894	DEPATT_00133894	DEPATT_00133894	DEPATT_00133894	DHFs	DEPATT_PROD002
DEPATT_00133895	DEPATT_00133916	DEPATT_00133895	DEPATT_00133916	DHFs	DEPATT_PROD002
DEPATT_00133917	DEPATT_00133937	DEPATT_00133917	DEPATT_00133937	DHFs	DEPATT_PROD002
DEPATT_00133938	DEPATT_00133938	DEPATT_00133938	DEPATT_00133938	DHFs	DEPATT_PROD002
DEPATT_00133939	DEPATT_00133954	DEPATT_00133939	DEPATT_00133954	DHFs	DEPATT_PROD002
DEPATT_00133955	DEPATT_00133955	DEPATT_00133955	DEPATT_00133955	DHFs	DEPATT_PROD002
DEPATT_00133956	DEPATT_00133965	DEPATT_00133956	DEPATT_00133965	DHFs	DEPATT_PROD002
DEPATT_00133966	DEPATT_00133966	DEPATT_00133966	DEPATT_00133966	DHFs	DEPATT_PROD002
DEPATT_00133967	DEPATT_00133967	DEPATT_00133967	DEPATT_00133967	DHFs	DEPATT_PROD002
DEPATT_00133968	DEPATT_00133973	DEPATT_00133968	DEPATT_00133973	DHFs	DEPATT_PROD002
DEPATT_00133974	DEPATT_00134001	DEPATT_00133974	DEPATT_00134001	DHFs	DEPATT_PROD002
DEPATT_00134002	DEPATT_00134002	DEPATT_00134002	DEPATT_00134002	DHFs	DEPATT_PROD002
DEPATT_00134003	DEPATT_00134003	DEPATT_00134003	DEPATT_00134003	DHFs	DEPATT_PROD002
DEPATT_00134004	DEPATT_00134004	DEPATT_00134004	DEPATT_00134004	DHFs	DEPATT_PROD002
DEPATT_00134005	DEPATT_00134005	DEPATT_00134005	DEPATT_00134005	DHFs	DEPATT_PROD002
DEPATT_00134006	DEPATT_00134006	DEPATT_00134006	DEPATT_00134006	DHFs	DEPATT_PROD002
DEPATT_00134007	DEPATT_00134007	DEPATT_00134007	DEPATT_00134007	DHFs	DEPATT_PROD002
DEPATT_00134008	DEPATT_00134008	DEPATT_00134008	DEPATT_00134008	DHFs	DEPATT_PROD002
DEPATT_00134009	DEPATT_00134024	DEPATT_00134009	DEPATT_00134024	DHFs	DEPATT_PROD002
DEPATT_00134025	DEPATT_00134025	DEPATT_00134025	DEPATT_00134025	DHFs	DEPATT_PROD002
DEPATT_00134026	DEPATT_00134035	DEPATT_00134026	DEPATT_00134035	DHFs	DEPATT_PROD002
DEPATT_00134036	DEPATT_00134036	DEPATT_00134036	DEPATT_00134036	DHFs	DEPATT_PROD002
DEPATT_00134037	DEPATT_00134037	DEPATT_00134037	DEPATT_00134037	DHFs	DEPATT_PROD002
DEPATT_00134038	DEPATT_00134038	DEPATT_00134038	DEPATT_00134038	DHFs	DEPATT_PROD002
DEPATT_00134039	DEPATT_00134039	DEPATT_00134039	DEPATT_00134039	DHFs	DEPATT_PROD002
DEPATT_00134040	DEPATT_00134055	DEPATT_00134040	DEPATT_00134055	DHFs	DEPATT_PROD002
DEPATT_00134056	DEPATT_00134056	DEPATT_00134056	DEPATT_00134056	DHFs	DEPATT_PROD002
DEPATT_00134057	DEPATT_00134057	DEPATT_00134057	DEPATT_00134057	DHFs	DEPATT_PROD002
DEPATT_00134058	DEPATT_00134058	DEPATT_00134058	DEPATT_00134058	DHFs	DEPATT_PROD002
DEPATT_00134059	DEPATT_00134059	DEPATT_00134059	DEPATT_00134059	DHFs	DEPATT_PROD002
DEPATT_00134060	DEPATT_00134060	DEPATT_00134060	DEPATT_00134060	DHFs	DEPATT_PROD002
DEPATT_00134061	DEPATT_00134061	DEPATT_00134061	DEPATT_00134061	DHFs	DEPATT_PROD002
DEPATT_00134062	DEPATT_00134062	DEPATT_00134062	DEPATT_00134062	DHFs	DEPATT_PROD002
DEPATT_00134063	DEPATT_00134087	DEPATT_00134063	DEPATT_00134087	DHFs	DEPATT_PROD002
DEPATT_00134088	DEPATT_00134089	DEPATT_00134088	DEPATT_00134089	DHFs	DEPATT_PROD002
DEPATT_00134090	DEPATT_00134091	DEPATT_00134090	DEPATT_00134091	DHFs	DEPATT_PROD002
DEPATT_00134092	DEPATT_00134209	DEPATT_00134092	DEPATT_00134209	DHFs	DEPATT_PROD002
DEPATT_00134210	DEPATT_00134211	DEPATT_00134210	DEPATT_00134211	DHFs	DEPATT_PROD002
DEPATT_00134212	DEPATT_00134217	DEPATT_00134212	DEPATT_00134217	DHFs	DEPATT_PROD002
DEPATT_00134218	DEPATT_00134218	DEPATT_00134218	DEPATT_00134218	DHFs	DEPATT_PROD002
DEPATT_00134219	DEPATT_00134219	DEPATT_00134219	DEPATT_00134219	DHFs	DEPATT_PROD002
DEPATT_00134220	DEPATT_00134257	DEPATT_00134220	DEPATT_00134257	DHFs	DEPATT_PROD002
DEPATT_00134258	DEPATT_00134298	DEPATT_00134258	DEPATT_00134298	DHFs	DEPATT_PROD002
DEPATT_00134299	DEPATT_00134299	DEPATT_00134299	DEPATT_00134299	DHFs	DEPATT_PROD002
DEPATT_00134300	DEPATT_00134307	DEPATT_00134300	DEPATT_00134307	DHFs	DEPATT_PROD002
DEPATT_00134308	DEPATT_00134308	DEPATT_00134308	DEPATT_00134308	DHFs	DEPATT_PROD002
DEPATT_00134309	DEPATT_00134309	DEPATT_00134309	DEPATT_00134309	DHFs	DEPATT_PROD002
DEPATT_00134310	DEPATT_00134310	DEPATT_00134310	DEPATT_00134310	DHFs	DEPATT_PROD002
DEPATT_00134311	DEPATT_00134311	DEPATT_00134311	DEPATT_00134311	DHFs	DEPATT_PROD002
DEPATT_00134312	DEPATT_00134312	DEPATT_00134312	DEPATT_00134312	DHFs	DEPATT_PROD002
DEPATT_00134313	DEPATT_00134315	DEPATT_00134313	DEPATT_00134315	DHFs	DEPATT_PROD002
DEPATT_00134316	DEPATT_00134316	DEPATT_00134316	DEPATT_00134316	DHFs	DEPATT_PROD002
DEPATT_00134317	DEPATT_00134584	DEPATT_00134317	DEPATT_00134584	DHFs	DEPATT_PROD002
DEPATT_00134585	DEPATT_00134586	DEPATT_00134585	DEPATT_00134586	DHFs	DEPATT_PROD002

PRODBEG	PRODEND	PRODBEGATT	PRODENDATT	CUSTODIAN	Production Volume
DEPATT_00134587	DEPATT_00134587	DEPATT_00134587	DEPATT_00134587	DHFs	DEPATT_PROD002
DEPATT_00134588	DEPATT_00134588	DEPATT_00134588	DEPATT_00134588	DHFs	DEPATT_PROD002
DEPATT_00134589	DEPATT_00134591	DEPATT_00134589	DEPATT_00134591	DHFs	DEPATT_PROD002
DEPATT_00134592	DEPATT_00134592	DEPATT_00134592	DEPATT_00134592	DHFs	DEPATT_PROD002
DEPATT_00134593	DEPATT_00134594	DEPATT_00134593	DEPATT_00134594	DHFs	DEPATT_PROD002
DEPATT_00134595	DEPATT_00134736	DEPATT_00134595	DEPATT_00134736	DHFs	DEPATT_PROD002
DEPATT_00134737	DEPATT_00134852	DEPATT_00134737	DEPATT_00134852	DHFs	DEPATT_PROD002
DEPATT_00134853	DEPATT_00134950	DEPATT_00134853	DEPATT_00134950	DHFs	DEPATT_PROD002
DEPATT_00134951	DEPATT_00135218	DEPATT_00134951	DEPATT_00135218	DHFs	DEPATT_PROD002
DEPATT_00135219	DEPATT_00135226	DEPATT_00135219	DEPATT_00135226	DHFs	DEPATT_PROD002
DEPATT_00135227	DEPATT_00135227	DEPATT_00135227	DEPATT_00135227	DHFs	DEPATT_PROD002
DEPATT_00135228	DEPATT_00135228	DEPATT_00135228	DEPATT_00135228	DHFs	DEPATT_PROD002
DEPATT_00135229	DEPATT_00135229	DEPATT_00135229	DEPATT_00135229	DHFs	DEPATT_PROD002
DEPATT_00135230	DEPATT_00135230	DEPATT_00135230	DEPATT_00135230	DHFs	DEPATT_PROD002
DEPATT_00135231	DEPATT_00135231	DEPATT_00135231	DEPATT_00135231	DHFs	DEPATT_PROD002
DEPATT_00135232	DEPATT_00135232	DEPATT_00135232	DEPATT_00135232	DHFs	DEPATT_PROD002
DEPATT_00135233	DEPATT_00135242	DEPATT_00135233	DEPATT_00135242	DHFs	DEPATT_PROD002
DEPATT_00135243	DEPATT_00135243	DEPATT_00135243	DEPATT_00135243	DHFs	DEPATT_PROD002
DEPATT_00135244	DEPATT_00135244	DEPATT_00135244	DEPATT_00135244	DHFs	DEPATT_PROD002
DEPATT_00135245	DEPATT_00135245	DEPATT_00135245	DEPATT_00135245	DHFs	DEPATT_PROD002
DEPATT_00135246	DEPATT_00135246	DEPATT_00135246	DEPATT_00135246	DHFs	DEPATT_PROD002
DEPATT_00135247	DEPATT_00135250	DEPATT_00135247	DEPATT_00135250	DHFs	DEPATT_PROD002
DEPATT_00135251	DEPATT_00135256	DEPATT_00135251	DEPATT_00135256	DHFs	DEPATT_PROD002
DEPATT_00135257	DEPATT_00135267	DEPATT_00135257	DEPATT_00135267	DHFs	DEPATT_PROD002
DEPATT_00135268	DEPATT_00135269	DEPATT_00135268	DEPATT_00135269	DHFs	DEPATT_PROD002
DEPATT_00135270	DEPATT_00135279	DEPATT_00135270	DEPATT_00135279	DHFs	DEPATT_PROD002
DEPATT_00135280	DEPATT_00135280	DEPATT_00135280	DEPATT_00135280	DHFs	DEPATT_PROD002
DEPATT_00135281	DEPATT_00135281	DEPATT_00135281	DEPATT_00135281	DHFs	DEPATT_PROD002
DEPATT_00135282	DEPATT_00135282	DEPATT_00135282	DEPATT_00135282	DHFs	DEPATT_PROD002
DEPATT_00135283	DEPATT_00135283	DEPATT_00135283	DEPATT_00135283	DHFs	DEPATT_PROD002
DEPATT_00135284	DEPATT_00135290	DEPATT_00135284	DEPATT_00135290	DHFs	DEPATT_PROD002
DEPATT_00135291	DEPATT_00135294	DEPATT_00135291	DEPATT_00135294	DHFs	DEPATT_PROD002
DEPATT_00135295	DEPATT_00135315	DEPATT_00135295	DEPATT_00135315	DHFs	DEPATT_PROD002
DEPATT_00135316	DEPATT_00135344	DEPATT_00135316	DEPATT_00135344	DHFs	DEPATT_PROD002
DEPATT_00135345	DEPATT_00135350	DEPATT_00135345	DEPATT_00135350	DHFs	DEPATT_PROD002
DEPATT_00135351	DEPATT_00135383	DEPATT_00135351	DEPATT_00135383	DHFs	DEPATT_PROD002
DEPATT_00135384	DEPATT_00135394	DEPATT_00135384	DEPATT_00135394	DHFs	DEPATT_PROD002
DEPATT_00135395	DEPATT_00135431	DEPATT_00135395	DEPATT_00135431	DHFs	DEPATT_PROD002
DEPATT_00135432	DEPATT_00135433	DEPATT_00135432	DEPATT_00135433	DHFs	DEPATT_PROD002
DEPATT_00135434	DEPATT_00135450	DEPATT_00135434	DEPATT_00135450	DHFs	DEPATT_PROD002
DEPATT_00135451	DEPATT_00135460	DEPATT_00135451	DEPATT_00135460	DHFs	DEPATT_PROD002
DEPATT_00135461	DEPATT_00135500	DEPATT_00135461	DEPATT_00135500	DHFs	DEPATT_PROD002
DEPATT_00135501	DEPATT_00135501	DEPATT_00135501	DEPATT_00135501	DHFs	DEPATT_PROD002
DEPATT_00135502	DEPATT_00135502	DEPATT_00135502	DEPATT_00135502	DHFs	DEPATT_PROD002
DEPATT_00135503	DEPATT_00135503	DEPATT_00135503	DEPATT_00135503	DHFs	DEPATT_PROD002
DEPATT_00135504	DEPATT_00135544	DEPATT_00135504	DEPATT_00135544	DHFs	DEPATT_PROD002
DEPATT_00135545	DEPATT_00135590	DEPATT_00135545	DEPATT_00135590	DHFs	DEPATT_PROD002
DEPATT_00135591	DEPATT_00135607	DEPATT_00135591	DEPATT_00135607	DHFs	DEPATT_PROD002
DEPATT_00135608	DEPATT_00135608	DEPATT_00135608	DEPATT_00135608	DHFs	DEPATT_PROD002
DEPATT_00135609	DEPATT_00135655	DEPATT_00135609	DEPATT_00135655	DHFs	DEPATT_PROD002
DEPATT_00135656	DEPATT_00135671	DEPATT_00135656	DEPATT_00135671	DHFs	DEPATT_PROD002
DEPATT_00135672	DEPATT_00135803	DEPATT_00135672	DEPATT_00135803	DHFs	DEPATT_PROD002
DEPATT_00135804	DEPATT_00135804	DEPATT_00135804	DEPATT_00135804	DHFs	DEPATT_PROD002
DEPATT_00135805	DEPATT_00135806	DEPATT_00135805	DEPATT_00135806	DHFs	DEPATT_PROD002
DEPATT_00135807	DEPATT_00135808	DEPATT_00135807	DEPATT_00135808	DHFs	DEPATT_PROD002
DEPATT_00135809	DEPATT_00135822	DEPATT_00135809	DEPATT_00135822	DHFs	DEPATT_PROD002
DEPATT_00135823	DEPATT_00135951	DEPATT_00135823	DEPATT_00135951	DHFs	DEPATT_PROD002

PRODBEG	PRODEND	PRODBEGATT	PRODENDATT	CUSTODIAN	Production Volume
DEPATT_00135952	DEPATT_00135961	DEPATT_00135952	DEPATT_00135962	DHFs	DEPATT_PROD002
DEPATT_00135962	DEPATT_00135962	DEPATT_00135952	DEPATT_00135962	DHFs	DEPATT_PROD002
DEPATT_00135963	DEPATT_00135978	DEPATT_00135963	DEPATT_00135979	DHFs	DEPATT_PROD002
DEPATT_00135979	DEPATT_00135979	DEPATT_00135963	DEPATT_00135979	DHFs	DEPATT_PROD002
DEPATT_00135980	DEPATT_00135985	DEPATT_00135980	DEPATT_00135985	DHFs	DEPATT_PROD002
DEPATT_00135986	DEPATT_00136029	DEPATT_00135986	DEPATT_00136029	DHFs	DEPATT_PROD002
DEPATT_00136030	DEPATT_00136030	DEPATT_00136030	DEPATT_00136030	DHFs	DEPATT_PROD002
DEPATT_00136031	DEPATT_00136036	DEPATT_00136031	DEPATT_00136037	DHFs	DEPATT_PROD002
DEPATT_00136037	DEPATT_00136037	DEPATT_00136031	DEPATT_00136037	DHFs	DEPATT_PROD002
DEPATT_00136038	DEPATT_00136077	DEPATT_00136038	DEPATT_00136077	DHFs	DEPATT_PROD002
DEPATT_00136078	DEPATT_00136116	DEPATT_00136078	DEPATT_00136116	DHFs	DEPATT_PROD002
DEPATT_00136117	DEPATT_00136124	DEPATT_00136117	DEPATT_00136124	DHFs	DEPATT_PROD002
DEPATT_00136125	DEPATT_00136125	DEPATT_00136125	DEPATT_00136125	DHFs	DEPATT_PROD002
DEPATT_00136126	DEPATT_00136126	DEPATT_00136126	DEPATT_00136127	DHFs	DEPATT_PROD002
DEPATT_00136127	DEPATT_00136127	DEPATT_00136126	DEPATT_00136127	DHFs	DEPATT_PROD002
DEPATT_00136128	DEPATT_00136128	DEPATT_00136128	DEPATT_00136128	DHFs	DEPATT_PROD002
DEPATT_00136129	DEPATT_00136133	DEPATT_00136129	DEPATT_00136133	DHFs	DEPATT_PROD002
DEPATT_00136134	DEPATT_00136158	DEPATT_00136134	DEPATT_00136158	DHFs	DEPATT_PROD002
DEPATT_00136159	DEPATT_00136172	DEPATT_00136159	DEPATT_00136172	DHFs	DEPATT_PROD002
DEPATT_00136173	DEPATT_00136190	DEPATT_00136173	DEPATT_00136190	DHFs	DEPATT_PROD002
DEPATT_00136191	DEPATT_00136206	DEPATT_00136191	DEPATT_00136206	DHFs	DEPATT_PROD002
DEPATT_00136207	DEPATT_00136213	DEPATT_00136207	DEPATT_00136213	DHFs	DEPATT_PROD002
DEPATT_00136214	DEPATT_00136220	DEPATT_00136214	DEPATT_00136220	DHFs	DEPATT_PROD002
DEPATT_00136221	DEPATT_00136244	DEPATT_00136221	DEPATT_00136244	DHFs	DEPATT_PROD002
DEPATT_00136245	DEPATT_00136267	DEPATT_00136245	DEPATT_00136267	DHFs	DEPATT_PROD002
DEPATT_00136268	DEPATT_00136274	DEPATT_00136268	DEPATT_00136274	DHFs	DEPATT_PROD002
DEPATT_00136275	DEPATT_00136281	DEPATT_00136275	DEPATT_00136281	DHFs	DEPATT_PROD002
DEPATT_00136282	DEPATT_00136305	DEPATT_00136282	DEPATT_00136305	DHFs	DEPATT_PROD002
DEPATT_00136306	DEPATT_00136327	DEPATT_00136306	DEPATT_00136327	DHFs	DEPATT_PROD002
DEPATT_00136328	DEPATT_00136345	DEPATT_00136328	DEPATT_00136345	DHFs	DEPATT_PROD002
DEPATT_00136346	DEPATT_00136361	DEPATT_00136346	DEPATT_00136361	DHFs	DEPATT_PROD002
DEPATT_00136362	DEPATT_00136362	DEPATT_00136362	DEPATT_00136362	DHFs	DEPATT_PROD002
DEPATT_00136363	DEPATT_00136363	DEPATT_00136363	DEPATT_00136363	DHFs	DEPATT_PROD002
DEPATT_00136364	DEPATT_00136372	DEPATT_00136364	DEPATT_00136372	DHFs	DEPATT_PROD002
DEPATT_00136373	DEPATT_00136381	DEPATT_00136373	DEPATT_00136381	DHFs	DEPATT_PROD002
DEPATT_00136382	DEPATT_00136390	DEPATT_00136382	DEPATT_00136390	DHFs	DEPATT_PROD002
DEPATT_00136391	DEPATT_00136399	DEPATT_00136391	DEPATT_00136399	DHFs	DEPATT_PROD002
DEPATT_00136400	DEPATT_00136400	DEPATT_00136400	DEPATT_00136400	DHFs	DEPATT_PROD002
DEPATT_00136401	DEPATT_00136401	DEPATT_00136401	DEPATT_00136401	DHFs	DEPATT_PROD002
DEPATT_00136402	DEPATT_00136402	DEPATT_00136402	DEPATT_00136403	DHFs	DEPATT_PROD002
DEPATT_00136403	DEPATT_00136403	DEPATT_00136402	DEPATT_00136403	DHFs	DEPATT_PROD002
DEPATT_00136404	DEPATT_00136404	DEPATT_00136404	DEPATT_00136404	DHFs	DEPATT_PROD002
DEPATT_00136405	DEPATT_00136413	DEPATT_00136405	DEPATT_00136413	DHFs	DEPATT_PROD002
DEPATT_00136414	DEPATT_00136422	DEPATT_00136414	DEPATT_00136422	DHFs	DEPATT_PROD002
DEPATT_00136423	DEPATT_00136423	DEPATT_00136423	DEPATT_00136423	DHFs	DEPATT_PROD002
DEPATT_00136424	DEPATT_00136429	DEPATT_00136424	DEPATT_00136429	DHFs	DEPATT_PROD002
DEPATT_00136430	DEPATT_00136438	DEPATT_00136430	DEPATT_00136438	DHFs	DEPATT_PROD002
DEPATT_00136439	DEPATT_00136439	DEPATT_00136439	DEPATT_00136439	DHFs	DEPATT_PROD002
DEPATT_00136440	DEPATT_00136440	DEPATT_00136440	DEPATT_00136440	DHFs	DEPATT_PROD002
DEPATT_00136441	DEPATT_00136441	DEPATT_00136441	DEPATT_00136441	DHFs	DEPATT_PROD002
DEPATT_00136442	DEPATT_00136458	DEPATT_00136442	DEPATT_00136458	DHFs	DEPATT_PROD002
DEPATT_00136459	DEPATT_00136460	DEPATT_00136459	DEPATT_00136460	DHFs	DEPATT_PROD002
DEPATT_00136461	DEPATT_00136463	DEPATT_00136461	DEPATT_00136463	DHFs	DEPATT_PROD002
DEPATT_00136464	DEPATT_00136466	DEPATT_00136464	DEPATT_00136466	DHFs	DEPATT_PROD002
DEPATT_00136467	DEPATT_00136467	DEPATT_00136467	DEPATT_00136467	DHFs	DEPATT_PROD002
DEPATT_00136468	DEPATT_00136468	DEPATT_00136468	DEPATT_00136468	DHFs	DEPATT_PROD002
DEPATT_00136469	DEPATT_00136469	DEPATT_00136469	DEPATT_00136469	DHFs	DEPATT_PROD002

PRODBEG	PRODEND	PRODBEGATT	PRODENDATT	CUSTODIAN	Production Volume
DEPATT_00136470	DEPATT_00136470	DEPATT_00136470	DEPATT_00136470	DHFs	DEPATT_PROD002
DEPATT_00136471	DEPATT_00136471	DEPATT_00136471	DEPATT_00136471	DHFs	DEPATT_PROD002
DEPATT_00136472	DEPATT_00136472	DEPATT_00136472	DEPATT_00136472	DHFs	DEPATT_PROD002
DEPATT_00136473	DEPATT_00136474	DEPATT_00136473	DEPATT_00136474	DHFs	DEPATT_PROD002
DEPATT_00136475	DEPATT_00136475	DEPATT_00136475	DEPATT_00136475	DHFs	DEPATT_PROD002
DEPATT_00136476	DEPATT_00136477	DEPATT_00136476	DEPATT_00136477	DHFs	DEPATT_PROD002
DEPATT_00136478	DEPATT_00136478	DEPATT_00136478	DEPATT_00136478	DHFs	DEPATT_PROD002
DEPATT_00136479	DEPATT_00136479	DEPATT_00136479	DEPATT_00136479	DHFs	DEPATT_PROD002
DEPATT_00136480	DEPATT_00136480	DEPATT_00136480	DEPATT_00136480	DHFs	DEPATT_PROD002
DEPATT_00136481	DEPATT_00136482	DEPATT_00136481	DEPATT_00136482	DHFs	DEPATT_PROD002
DEPATT_00136483	DEPATT_00136484	DEPATT_00136483	DEPATT_00136484	DHFs	DEPATT_PROD002
DEPATT_00136485	DEPATT_00136486	DEPATT_00136485	DEPATT_00136486	DHFs	DEPATT_PROD002
DEPATT_00136487	DEPATT_00136487	DEPATT_00136487	DEPATT_00136487	DHFs	DEPATT_PROD002
DEPATT_00136488	DEPATT_00136499	DEPATT_00136488	DEPATT_00136499	DHFs	DEPATT_PROD002
DEPATT_00136500	DEPATT_00136511	DEPATT_00136500	DEPATT_00136511	DHFs	DEPATT_PROD002
DEPATT_00136512	DEPATT_00136523	DEPATT_00136512	DEPATT_00136523	DHFs	DEPATT_PROD002
DEPATT_00136524	DEPATT_00136528	DEPATT_00136524	DEPATT_00136528	DHFs	DEPATT_PROD002
DEPATT_00136529	DEPATT_00136532	DEPATT_00136529	DEPATT_00136532	DHFs	DEPATT_PROD002
DEPATT_00136533	DEPATT_00136536	DEPATT_00136533	DEPATT_00136536	DHFs	DEPATT_PROD002
DEPATT_00136537	DEPATT_00136540	DEPATT_00136537	DEPATT_00136540	DHFs	DEPATT_PROD002
DEPATT_00136541	DEPATT_00136544	DEPATT_00136541	DEPATT_00136544	DHFs	DEPATT_PROD002
DEPATT_00136545	DEPATT_00136548	DEPATT_00136545	DEPATT_00136548	DHFs	DEPATT_PROD002
DEPATT_00136549	DEPATT_00136559	DEPATT_00136549	DEPATT_00136559	DHFs	DEPATT_PROD002
DEPATT_00136560	DEPATT_00136570	DEPATT_00136560	DEPATT_00136570	DHFs	DEPATT_PROD002
DEPATT_00136571	DEPATT_00136666	DEPATT_00136571	DEPATT_00136666	DHFs	DEPATT_PROD002
DEPATT_00136667	DEPATT_00136762	DEPATT_00136667	DEPATT_00136762	DHFs	DEPATT_PROD002
DEPATT_00136763	DEPATT_00136766	DEPATT_00136763	DEPATT_00136766	DHFs	DEPATT_PROD002
DEPATT_00136767	DEPATT_00136770	DEPATT_00136767	DEPATT_00136770	DHFs	DEPATT_PROD002
DEPATT_00136771	DEPATT_00136876	DEPATT_00136771	DEPATT_00136876	DHFs	DEPATT_PROD002
DEPATT_00136877	DEPATT_00136880	DEPATT_00136877	DEPATT_00136880	DHFs	DEPATT_PROD002
DEPATT_00136881	DEPATT_00136884	DEPATT_00136881	DEPATT_00136884	DHFs	DEPATT_PROD002
DEPATT_00136885	DEPATT_00136889	DEPATT_00136885	DEPATT_00136889	DHFs	DEPATT_PROD002
DEPATT_00136890	DEPATT_00136893	DEPATT_00136890	DEPATT_00136893	DHFs	DEPATT_PROD002
DEPATT_00136894	DEPATT_00136896	DEPATT_00136894	DEPATT_00136896	DHFs	DEPATT_PROD002
DEPATT_00136897	DEPATT_00136899	DEPATT_00136897	DEPATT_00136899	DHFs	DEPATT_PROD002
DEPATT_00136900	DEPATT_00136902	DEPATT_00136900	DEPATT_00136902	DHFs	DEPATT_PROD002
DEPATT_00136903	DEPATT_00136905	DEPATT_00136903	DEPATT_00136905	DHFs	DEPATT_PROD002
DEPATT_00136906	DEPATT_00136906	DEPATT_00136906	DEPATT_00136906	DHFs	DEPATT_PROD002
DEPATT_00136907	DEPATT_00136909	DEPATT_00136907	DEPATT_00136909	DHFs	DEPATT_PROD002
DEPATT_00136910	DEPATT_00136912	DEPATT_00136910	DEPATT_00136912	DHFs	DEPATT_PROD002
DEPATT_00136913	DEPATT_00136915	DEPATT_00136913	DEPATT_00136915	DHFs	DEPATT_PROD002
DEPATT_00136916	DEPATT_00136918	DEPATT_00136916	DEPATT_00136918	DHFs	DEPATT_PROD002
DEPATT_00136919	DEPATT_00136921	DEPATT_00136919	DEPATT_00136921	DHFs	DEPATT_PROD002
DEPATT_00136922	DEPATT_00136924	DEPATT_00136922	DEPATT_00136924	DHFs	DEPATT_PROD002
DEPATT_00136925	DEPATT_00136927	DEPATT_00136925	DEPATT_00136927	DHFs	DEPATT_PROD002
DEPATT_00136928	DEPATT_00136931	DEPATT_00136928	DEPATT_00136931	DHFs	DEPATT_PROD002
DEPATT_00136932	DEPATT_00136934	DEPATT_00136932	DEPATT_00136934	DHFs	DEPATT_PROD002
DEPATT_00136935	DEPATT_00136937	DEPATT_00136935	DEPATT_00136937	DHFs	DEPATT_PROD002
DEPATT_00136938	DEPATT_00136940	DEPATT_00136938	DEPATT_00136940	DHFs	DEPATT_PROD002
DEPATT_00136941	DEPATT_00136943	DEPATT_00136941	DEPATT_00136943	DHFs	DEPATT_PROD002
DEPATT_00136944	DEPATT_00136946	DEPATT_00136944	DEPATT_00136946	DHFs	DEPATT_PROD002
DEPATT_00136947	DEPATT_00136949	DEPATT_00136947	DEPATT_00136949	DHFs	DEPATT_PROD002
DEPATT_00136950	DEPATT_00136952	DEPATT_00136950	DEPATT_00136952	DHFs	DEPATT_PROD002
DEPATT_00136953	DEPATT_00136958	DEPATT_00136953	DEPATT_00136958	DHFs	DEPATT_PROD002
DEPATT_00136959	DEPATT_00136962	DEPATT_00136959	DEPATT_00136962	DHFs	DEPATT_PROD002
DEPATT_00136963	DEPATT_00136966	DEPATT_00136963	DEPATT_00136966	DHFs	DEPATT_PROD002
DEPATT_00136967	DEPATT_00136970	DEPATT_00136967	DEPATT_00136970	DHFs	DEPATT_PROD002

PRODBEG	PRODEND	PRODBEGATT	PRODENDATT	CUSTODIAN	Production Volume
DEPATT_00136971	DEPATT_00136973	DEPATT_00136971	DEPATT_00136973	DHFs	DEPATT_PROD002
DEPATT_00136974	DEPATT_00136976	DEPATT_00136974	DEPATT_00136976	DHFs	DEPATT_PROD002
DEPATT_00136977	DEPATT_00136979	DEPATT_00136977	DEPATT_00136979	DHFs	DEPATT_PROD002
DEPATT_00136980	DEPATT_00136982	DEPATT_00136980	DEPATT_00136982	DHFs	DEPATT_PROD002
DEPATT_00136983	DEPATT_00136986	DEPATT_00136983	DEPATT_00136986	DHFs	DEPATT_PROD002
DEPATT_00136987	DEPATT_00136989	DEPATT_00136987	DEPATT_00136989	DHFs	DEPATT_PROD002
DEPATT_00136990	DEPATT_00136992	DEPATT_00136990	DEPATT_00136992	DHFs	DEPATT_PROD002
DEPATT_00136993	DEPATT_00136995	DEPATT_00136993	DEPATT_00136995	DHFs	DEPATT_PROD002
DEPATT_00136996	DEPATT_00136998	DEPATT_00136996	DEPATT_00136998	DHFs	DEPATT_PROD002
DEPATT_00136999	DEPATT_00137001	DEPATT_00136999	DEPATT_00137001	DHFs	DEPATT_PROD002
DEPATT_00137002	DEPATT_00137004	DEPATT_00137002	DEPATT_00137004	DHFs	DEPATT_PROD002
DEPATT_00137005	DEPATT_00137007	DEPATT_00137005	DEPATT_00137007	DHFs	DEPATT_PROD002
DEPATT_00137008	DEPATT_00137010	DEPATT_00137008	DEPATT_00137010	DHFs	DEPATT_PROD002
DEPATT_00137011	DEPATT_00137013	DEPATT_00137011	DEPATT_00137013	DHFs	DEPATT_PROD002
DEPATT_00137014	DEPATT_00137016	DEPATT_00137014	DEPATT_00137016	DHFs	DEPATT_PROD002
DEPATT_00137017	DEPATT_00137019	DEPATT_00137017	DEPATT_00137019	DHFs	DEPATT_PROD002
DEPATT_00137020	DEPATT_00137023	DEPATT_00137020	DEPATT_00137023	DHFs	DEPATT_PROD002
DEPATT_00137024	DEPATT_00137026	DEPATT_00137024	DEPATT_00137026	DHFs	DEPATT_PROD002
DEPATT_00137027	DEPATT_00137029	DEPATT_00137027	DEPATT_00137029	DHFs	DEPATT_PROD002
DEPATT_00137030	DEPATT_00137032	DEPATT_00137030	DEPATT_00137032	DHFs	DEPATT_PROD002
DEPATT_00137033	DEPATT_00137036	DEPATT_00137033	DEPATT_00137036	DHFs	DEPATT_PROD002
DEPATT_00137037	DEPATT_00137039	DEPATT_00137037	DEPATT_00137039	DHFs	DEPATT_PROD002
DEPATT_00137040	DEPATT_00137042	DEPATT_00137040	DEPATT_00137042	DHFs	DEPATT_PROD002
DEPATT_00137043	DEPATT_00137045	DEPATT_00137043	DEPATT_00137045	DHFs	DEPATT_PROD002
DEPATT_00137046	DEPATT_00137048	DEPATT_00137046	DEPATT_00137048	DHFs	DEPATT_PROD002
DEPATT_00137049	DEPATT_00137051	DEPATT_00137049	DEPATT_00137051	DHFs	DEPATT_PROD002
DEPATT_00137052	DEPATT_00137054	DEPATT_00137052	DEPATT_00137054	DHFs	DEPATT_PROD002
DEPATT_00137055	DEPATT_00137057	DEPATT_00137055	DEPATT_00137057	DHFs	DEPATT_PROD002
DEPATT_00137058	DEPATT_00137061	DEPATT_00137058	DEPATT_00137061	DHFs	DEPATT_PROD002
DEPATT_00137062	DEPATT_00137064	DEPATT_00137062	DEPATT_00137064	DHFs	DEPATT_PROD002
DEPATT_00137065	DEPATT_00137067	DEPATT_00137065	DEPATT_00137067	DHFs	DEPATT_PROD002
DEPATT_00137068	DEPATT_00137070	DEPATT_00137068	DEPATT_00137070	DHFs	DEPATT_PROD002
DEPATT_00137071	DEPATT_00137074	DEPATT_00137071	DEPATT_00137074	DHFs	DEPATT_PROD002
DEPATT_00137075	DEPATT_00137079	DEPATT_00137075	DEPATT_00137079	DHFs	DEPATT_PROD002
DEPATT_00137080	DEPATT_00137082	DEPATT_00137080	DEPATT_00137082	DHFs	DEPATT_PROD002
DEPATT_00137083	DEPATT_00137085	DEPATT_00137083	DEPATT_00137085	DHFs	DEPATT_PROD002
DEPATT_00137086	DEPATT_00137088	DEPATT_00137086	DEPATT_00137088	DHFs	DEPATT_PROD002
DEPATT_00137089	DEPATT_00137091	DEPATT_00137089	DEPATT_00137091	DHFs	DEPATT_PROD002
DEPATT_00137092	DEPATT_00137095	DEPATT_00137092	DEPATT_00137095	DHFs	DEPATT_PROD002
DEPATT_00137096	DEPATT_00137099	DEPATT_00137096	DEPATT_00137099	DHFs	DEPATT_PROD002
DEPATT_00137100	DEPATT_00137103	DEPATT_00137100	DEPATT_00137103	DHFs	DEPATT_PROD002
DEPATT_00137104	DEPATT_00137106	DEPATT_00137104	DEPATT_00137106	DHFs	DEPATT_PROD002
DEPATT_00137107	DEPATT_00137110	DEPATT_00137107	DEPATT_00137110	DHFs	DEPATT_PROD002
DEPATT_00137111	DEPATT_00137114	DEPATT_00137111	DEPATT_00137114	DHFs	DEPATT_PROD002
DEPATT_00137115	DEPATT_00137214	DEPATT_00137115	DEPATT_00137214	DHFs	DEPATT_PROD002
DEPATT_00137215	DEPATT_00137218	DEPATT_00137215	DEPATT_00137218	DHFs	DEPATT_PROD002
DEPATT_00137219	DEPATT_00137219	DEPATT_00137219	DEPATT_00137219	DHFs	DEPATT_PROD002
DEPATT_00137220	DEPATT_00137222	DEPATT_00137220	DEPATT_00137222	DHFs	DEPATT_PROD002
DEPATT_00137223	DEPATT_00137226	DEPATT_00137223	DEPATT_00137226	DHFs	DEPATT_PROD002
DEPATT_00137227	DEPATT_00137230	DEPATT_00137227	DEPATT_00137230	DHFs	DEPATT_PROD002
DEPATT_00137231	DEPATT_00137236	DEPATT_00137231	DEPATT_00137236	DHFs	DEPATT_PROD002
DEPATT_00137237	DEPATT_00137239	DEPATT_00137237	DEPATT_00137239	DHFs	DEPATT_PROD002
DEPATT_00137240	DEPATT_00137242	DEPATT_00137240	DEPATT_00137242	DHFs	DEPATT_PROD002
DEPATT_00137243	DEPATT_00137245	DEPATT_00137243	DEPATT_00137245	DHFs	DEPATT_PROD002
DEPATT_00137246	DEPATT_00137248	DEPATT_00137246	DEPATT_00137248	DHFs	DEPATT_PROD002
DEPATT_00137249	DEPATT_00137252	DEPATT_00137249	DEPATT_00137252	DHFs	DEPATT_PROD002
DEPATT_00137253	DEPATT_00137257	DEPATT_00137253	DEPATT_00137257	DHFs	DEPATT_PROD002

PRODBEG	PRODEND	PRODBEGATT	PRODENDATT	CUSTODIAN	Production Volume
DEPATT_00137258	DEPATT_00137261	DEPATT_00137258	DEPATT_00137261	DHFs	DEPATT_PROD002
DEPATT_00137262	DEPATT_00137265	DEPATT_00137262	DEPATT_00137265	DHFs	DEPATT_PROD002
DEPATT_00137266	DEPATT_00137269	DEPATT_00137266	DEPATT_00137269	DHFs	DEPATT_PROD002
DEPATT_00137270	DEPATT_00137273	DEPATT_00137270	DEPATT_00137273	DHFs	DEPATT_PROD002
DEPATT_00137274	DEPATT_00137285	DEPATT_00137274	DEPATT_00137285	DHFs	DEPATT_PROD002
DEPATT_00137286	DEPATT_00137289	DEPATT_00137286	DEPATT_00137289	DHFs	DEPATT_PROD002
DEPATT_00137290	DEPATT_00137293	DEPATT_00137290	DEPATT_00137293	DHFs	DEPATT_PROD002
DEPATT_00137294	DEPATT_00137296	DEPATT_00137294	DEPATT_00137296	DHFs	DEPATT_PROD002
DEPATT_00137297	DEPATT_00137299	DEPATT_00137297	DEPATT_00137299	DHFs	DEPATT_PROD002
DEPATT_00137300	DEPATT_00137303	DEPATT_00137300	DEPATT_00137303	DHFs	DEPATT_PROD002
DEPATT_00137304	DEPATT_00137306	DEPATT_00137304	DEPATT_00137306	DHFs	DEPATT_PROD002
DEPATT_00137307	DEPATT_00137309	DEPATT_00137307	DEPATT_00137309	DHFs	DEPATT_PROD002
DEPATT_00137310	DEPATT_00137312	DEPATT_00137310	DEPATT_00137312	DHFs	DEPATT_PROD002
DEPATT_00137313	DEPATT_00137317	DEPATT_00137313	DEPATT_00137317	DHFs	DEPATT_PROD002
DEPATT_00137318	DEPATT_00137322	DEPATT_00137318	DEPATT_00137322	DHFs	DEPATT_PROD002
DEPATT_00137323	DEPATT_00137326	DEPATT_00137323	DEPATT_00137326	DHFs	DEPATT_PROD002
DEPATT_00137327	DEPATT_00137330	DEPATT_00137327	DEPATT_00137330	DHFs	DEPATT_PROD002
DEPATT_00137331	DEPATT_00137333	DEPATT_00137331	DEPATT_00137333	DHFs	DEPATT_PROD002
DEPATT_00137334	DEPATT_00137336	DEPATT_00137334	DEPATT_00137336	DHFs	DEPATT_PROD002
DEPATT_00137337	DEPATT_00137340	DEPATT_00137337	DEPATT_00137340	DHFs	DEPATT_PROD002
DEPATT_00137341	DEPATT_00137343	DEPATT_00137341	DEPATT_00137343	DHFs	DEPATT_PROD002
DEPATT_00137344	DEPATT_00137346	DEPATT_00137344	DEPATT_00137346	DHFs	DEPATT_PROD002
DEPATT_00137347	DEPATT_00137349	DEPATT_00137347	DEPATT_00137349	DHFs	DEPATT_PROD002
DEPATT_00137350	DEPATT_00137352	DEPATT_00137350	DEPATT_00137352	DHFs	DEPATT_PROD002
DEPATT_00137353	DEPATT_00137355	DEPATT_00137353	DEPATT_00137355	DHFs	DEPATT_PROD002
DEPATT_00137356	DEPATT_00137359	DEPATT_00137356	DEPATT_00137359	DHFs	DEPATT_PROD002
DEPATT_00137360	DEPATT_00137363	DEPATT_00137360	DEPATT_00137363	DHFs	DEPATT_PROD002
DEPATT_00137364	DEPATT_00137366	DEPATT_00137364	DEPATT_00137366	DHFs	DEPATT_PROD002
DEPATT_00137367	DEPATT_00137369	DEPATT_00137367	DEPATT_00137369	DHFs	DEPATT_PROD002
DEPATT_00137370	DEPATT_00137373	DEPATT_00137370	DEPATT_00137373	DHFs	DEPATT_PROD002
DEPATT_00137374	DEPATT_00137377	DEPATT_00137374	DEPATT_00137377	DHFs	DEPATT_PROD002
DEPATT_00137378	DEPATT_00137381	DEPATT_00137378	DEPATT_00137381	DHFs	DEPATT_PROD002
DEPATT_00137382	DEPATT_00137385	DEPATT_00137382	DEPATT_00137385	DHFs	DEPATT_PROD002
DEPATT_00137386	DEPATT_00137386	DEPATT_00137386	DEPATT_00137386	DHFs	DEPATT_PROD002
DEPATT_00137387	DEPATT_00137387	DEPATT_00137387	DEPATT_00137387	DHFs	DEPATT_PROD002
DEPATT_00137388	DEPATT_00137388	DEPATT_00137388	DEPATT_00137388	DHFs	DEPATT_PROD002
DEPATT_00137389	DEPATT_00137390	DEPATT_00137389	DEPATT_00137390	DHFs	DEPATT_PROD002
DEPATT_00137391	DEPATT_00137392	DEPATT_00137391	DEPATT_00137392	DHFs	DEPATT_PROD002
DEPATT_00218392	DEPATT_00218405	DEPATT_00218392	DEPATT_00218405	DHFs	DEPATT_PROD003
DEPATT_00218406	DEPATT_00218418	DEPATT_00218406	DEPATT_00218418	DHFs	DEPATT_PROD003
DEPATT_00218419	DEPATT_00218424	DEPATT_00218419	DEPATT_00218424	DHFs	DEPATT_PROD003
DEPATT_00218425	DEPATT_00218468	DEPATT_00218425	DEPATT_00218468	DHFs	DEPATT_PROD003
DEPATT_00218469	DEPATT_00218473	DEPATT_00218469	DEPATT_00218473	DHFs	DEPATT_PROD003
DEPATT_00218474	DEPATT_00218476	DEPATT_00218474	DEPATT_00218476	DHFs	DEPATT_PROD003
DEPATT_00218477	DEPATT_00218505	DEPATT_00218477	DEPATT_00218505	DHFs	DEPATT_PROD003
DEPATT_00218506	DEPATT_00218506	DEPATT_00218506	DEPATT_00218506	DHFs	DEPATT_PROD003
DEPATT_00218507	DEPATT_00218507	DEPATT_00218507	DEPATT_00218508	DHFs	DEPATT_PROD003
DEPATT_00218508	DEPATT_00218508	DEPATT_00218507	DEPATT_00218508	DHFs	DEPATT_PROD003
DEPATT_00218509	DEPATT_00218519	DEPATT_00218509	DEPATT_00218519	DHFs	DEPATT_PROD003
DEPATT_00218520	DEPATT_00218637	DEPATT_00218520	DEPATT_00218637	DHFs	DEPATT_PROD003
DEPATT_00218638	DEPATT_00218690	DEPATT_00218638	DEPATT_00218690	DHFs	DEPATT_PROD003
DEPATT_00218691	DEPATT_00218797	DEPATT_00218691	DEPATT_00218797	DHFs	DEPATT_PROD003
DEPATT_00218798	DEPATT_00218804	DEPATT_00218798	DEPATT_00218804	DHFs	DEPATT_PROD003
DEPATT_00218805	DEPATT_00218819	DEPATT_00218805	DEPATT_00218819	DHFs	DEPATT_PROD003
DEPATT_00218820	DEPATT_00218826	DEPATT_00218820	DEPATT_00218826	DHFs	DEPATT_PROD003
DEPATT_00218827	DEPATT_00218879	DEPATT_00218827	DEPATT_00218879	DHFs	DEPATT_PROD003
DEPATT_00218880	DEPATT_00218892	DEPATT_00218880	DEPATT_00218892	DHFs	DEPATT_PROD003

PRODBEG	PRODEND	PRODBEGATT	PRODENDATT	CUSTODIAN	Production Volume
DEPATT_00218893	DEPATT_00218893	DEPATT_00218893	DEPATT_00218893	DHFs	DEPATT_PROD003
DEPATT_00218894	DEPATT_00218902	DEPATT_00218894	DEPATT_00218902	DHFs	DEPATT_PROD003
DEPATT_00218903	DEPATT_00218922	DEPATT_00218903	DEPATT_00218922	DHFs	DEPATT_PROD003
DEPATT_00218923	DEPATT_00218929	DEPATT_00218923	DEPATT_00218929	DHFs	DEPATT_PROD003
DEPATT_00218930	DEPATT_00218938	DEPATT_00218930	DEPATT_00218938	DHFs	DEPATT_PROD003
DEPATT_00218939	DEPATT_00218950	DEPATT_00218939	DEPATT_00218950	DHFs	DEPATT_PROD003
DEPATT_00218951	DEPATT_00218961	DEPATT_00218951	DEPATT_00218961	DHFs	DEPATT_PROD003
DEPATT_00218962	DEPATT_00218972	DEPATT_00218962	DEPATT_00218972	DHFs	DEPATT_PROD003
DEPATT_00218973	DEPATT_00218985	DEPATT_00218973	DEPATT_00218985	DHFs	DEPATT_PROD003
DEPATT_00218986	DEPATT_00218986	DEPATT_00218986	DEPATT_00218986	DHFs	DEPATT_PROD003
DEPATT_00218987	DEPATT_00219003	DEPATT_00218987	DEPATT_00219003	DHFs	DEPATT_PROD003
DEPATT_00219004	DEPATT_00219005	DEPATT_00219004	DEPATT_00219005	DHFs	DEPATT_PROD003
DEPATT_00219006	DEPATT_00219006	DEPATT_00219006	DEPATT_00219006	DHFs	DEPATT_PROD003
DEPATT_00219007	DEPATT_00219007	DEPATT_00219007	DEPATT_00219007	DHFs	DEPATT_PROD003
DEPATT_00219008	DEPATT_00219008	DEPATT_00219008	DEPATT_00219008	DHFs	DEPATT_PROD003
DEPATT_00219009	DEPATT_00219009	DEPATT_00219009	DEPATT_00219009	DHFs	DEPATT_PROD003
DEPATT_00219010	DEPATT_00219010	DEPATT_00219010	DEPATT_00219010	DHFs	DEPATT_PROD003
DEPATT_00219011	DEPATT_00219011	DEPATT_00219011	DEPATT_00219011	DHFs	DEPATT_PROD003
DEPATT_00219012	DEPATT_00219012	DEPATT_00219012	DEPATT_00219012	DHFs	DEPATT_PROD003
DEPATT_00219013	DEPATT_00219014	DEPATT_00219013	DEPATT_00219014	DHFs	DEPATT_PROD003
DEPATT_00219015	DEPATT_00219015	DEPATT_00219015	DEPATT_00219015	DHFs	DEPATT_PROD003
DEPATT_00219016	DEPATT_00219020	DEPATT_00219016	DEPATT_00219020	DHFs	DEPATT_PROD003
DEPATT_00219021	DEPATT_00219021	DEPATT_00219021	DEPATT_00219021	DHFs	DEPATT_PROD003
DEPATT_00219022	DEPATT_00219022	DEPATT_00219022	DEPATT_00219022	DHFs	DEPATT_PROD003
DEPATT_00219023	DEPATT_00219023	DEPATT_00219023	DEPATT_00219023	DHFs	DEPATT_PROD003
DEPATT_00219024	DEPATT_00219024	DEPATT_00219024	DEPATT_00219024	DHFs	DEPATT_PROD003
DEPATT_00219025	DEPATT_00219029	DEPATT_00219025	DEPATT_00219029	DHFs	DEPATT_PROD003
DEPATT_00219030	DEPATT_00219030	DEPATT_00219030	DEPATT_00219030	DHFs	DEPATT_PROD003
DEPATT_00219031	DEPATT_00219031	DEPATT_00219031	DEPATT_00219031	DHFs	DEPATT_PROD003
DEPATT_00219032	DEPATT_00219032	DEPATT_00219032	DEPATT_00219032	DHFs	DEPATT_PROD003
DEPATT_00219033	DEPATT_00219033	DEPATT_00219033	DEPATT_00219033	DHFs	DEPATT_PROD003
DEPATT_00219034	DEPATT_00219034	DEPATT_00219034	DEPATT_00219034	DHFs	DEPATT_PROD003
DEPATT_00219035	DEPATT_00219035	DEPATT_00219035	DEPATT_00219035	DHFs	DEPATT_PROD003
DEPATT_00219036	DEPATT_00219036	DEPATT_00219036	DEPATT_00219036	DHFs	DEPATT_PROD003
DEPATT_00219037	DEPATT_00219037	DEPATT_00219037	DEPATT_00219037	DHFs	DEPATT_PROD003
DEPATT_00219038	DEPATT_00219038	DEPATT_00219038	DEPATT_00219038	DHFs	DEPATT_PROD003
DEPATT_00219039	DEPATT_00219043	DEPATT_00219039	DEPATT_00219043	DHFs	DEPATT_PROD003
DEPATT_00219044	DEPATT_00219044	DEPATT_00219044	DEPATT_00219044	DHFs	DEPATT_PROD003
DEPATT_00219045	DEPATT_00219045	DEPATT_00219045	DEPATT_00219045	DHFs	DEPATT_PROD003
DEPATT_00219046	DEPATT_00219046	DEPATT_00219046	DEPATT_00219046	DHFs	DEPATT_PROD003
DEPATT_00219047	DEPATT_00219047	DEPATT_00219047	DEPATT_00219047	DHFs	DEPATT_PROD003
DEPATT_00219048	DEPATT_00219048	DEPATT_00219048	DEPATT_00219048	DHFs	DEPATT_PROD003
DEPATT_00219049	DEPATT_00219049	DEPATT_00219049	DEPATT_00219049	DHFs	DEPATT_PROD003
DEPATT_00219050	DEPATT_00219050	DEPATT_00219050	DEPATT_00219050	DHFs	DEPATT_PROD003
DEPATT_00219051	DEPATT_00219055	DEPATT_00219051	DEPATT_00219055	DHFs	DEPATT_PROD003
DEPATT_00219056	DEPATT_00219056	DEPATT_00219056	DEPATT_00219056	DHFs	DEPATT_PROD003
DEPATT_00219057	DEPATT_00219057	DEPATT_00219057	DEPATT_00219057	DHFs	DEPATT_PROD003
DEPATT_00219058	DEPATT_00219058	DEPATT_00219058	DEPATT_00219058	DHFs	DEPATT_PROD003
DEPATT_00219059	DEPATT_00219059	DEPATT_00219059	DEPATT_00219059	DHFs	DEPATT_PROD003
DEPATT_00219060	DEPATT_00219060	DEPATT_00219060	DEPATT_00219060	DHFs	DEPATT_PROD003
DEPATT_00219061	DEPATT_00219065	DEPATT_00219061	DEPATT_00219065	DHFs	DEPATT_PROD003
DEPATT_00219066	DEPATT_00219066	DEPATT_00219066	DEPATT_00219066	DHFs	DEPATT_PROD003
DEPATT_00219067	DEPATT_00219067	DEPATT_00219067	DEPATT_00219067	DHFs	DEPATT_PROD003
DEPATT_00219068	DEPATT_00219068	DEPATT_00219068	DEPATT_00219068	DHFs	DEPATT_PROD003
DEPATT_00219069	DEPATT_00219069	DEPATT_00219069	DEPATT_00219069	DHFs	DEPATT_PROD003
DEPATT_00219070	DEPATT_00219070	DEPATT_00219070	DEPATT_00219070	DHFs	DEPATT_PROD003
DEPATT_00219071	DEPATT_00219071	DEPATT_00219071	DEPATT_00219071	DHFs	DEPATT_PROD003

PRODBEG	PRODEND	PRODBEGATT	PRODENDATT	CUSTODIAN	Production Volume
DEPATT_00219072	DEPATT_00219072	DEPATT_00219072	DEPATT_00219072	DHFs	DEPATT_PROD003
DEPATT_00219073	DEPATT_00219073	DEPATT_00219073	DEPATT_00219073	DHFs	DEPATT_PROD003
DEPATT_00219074	DEPATT_00219074	DEPATT_00219074	DEPATT_00219074	DHFs	DEPATT_PROD003
DEPATT_00219075	DEPATT_00219075	DEPATT_00219075	DEPATT_00219075	DHFs	DEPATT_PROD003
DEPATT_00219076	DEPATT_00219076	DEPATT_00219076	DEPATT_00219076	DHFs	DEPATT_PROD003
DEPATT_00219077	DEPATT_00219087	DEPATT_00219077	DEPATT_00219087	DHFs	DEPATT_PROD003
DEPATT_00219088	DEPATT_00219096	DEPATT_00219088	DEPATT_00219096	DHFs	DEPATT_PROD003
DEPATT_00219097	DEPATT_00219116	DEPATT_00219097	DEPATT_00219116	DHFs	DEPATT_PROD003
DEPATT_00219117	DEPATT_00219123	DEPATT_00219117	DEPATT_00219123	DHFs	DEPATT_PROD003
DEPATT_00219124	DEPATT_00219132	DEPATT_00219124	DEPATT_00219132	DHFs	DEPATT_PROD003
DEPATT_00219133	DEPATT_00219144	DEPATT_00219133	DEPATT_00219144	DHFs	DEPATT_PROD003
DEPATT_00219145	DEPATT_00219155	DEPATT_00219145	DEPATT_00219155	DHFs	DEPATT_PROD003
DEPATT_00219156	DEPATT_00219168	DEPATT_00219156	DEPATT_00219168	DHFs	DEPATT_PROD003
DEPATT_00219169	DEPATT_00219182	DEPATT_00219169	DEPATT_00219182	DHFs	DEPATT_PROD003
DEPATT_00219183	DEPATT_00219196	DEPATT_00219183	DEPATT_00219196	DHFs	DEPATT_PROD003
DEPATT_00219197	DEPATT_00219209	DEPATT_00219197	DEPATT_00219209	DHFs	DEPATT_PROD003
DEPATT_00219210	DEPATT_00219222	DEPATT_00219210	DEPATT_00219222	DHFs	DEPATT_PROD003
DEPATT_00219223	DEPATT_00219223	DEPATT_00219223	DEPATT_00219223	DHFs	DEPATT_PROD003
DEPATT_00219224	DEPATT_00219224	DEPATT_00219224	DEPATT_00219224	DHFs	DEPATT_PROD003
DEPATT_00219225	DEPATT_00219225	DEPATT_00219225	DEPATT_00219225	DHFs	DEPATT_PROD003
DEPATT_00219226	DEPATT_00219226	DEPATT_00219226	DEPATT_00219226	DHFs	DEPATT_PROD003
DEPATT_00219227	DEPATT_00219227	DEPATT_00219227	DEPATT_00219227	DHFs	DEPATT_PROD003
DEPATT_00219228	DEPATT_00219228	DEPATT_00219228	DEPATT_00219228	DHFs	DEPATT_PROD003
DEPATT_00219229	DEPATT_00219229	DEPATT_00219229	DEPATT_00219229	DHFs	DEPATT_PROD003
DEPATT_00219230	DEPATT_00219230	DEPATT_00219230	DEPATT_00219230	DHFs	DEPATT_PROD003
DEPATT_00219231	DEPATT_00219231	DEPATT_00219231	DEPATT_00219231	DHFs	DEPATT_PROD003
DEPATT_00219232	DEPATT_00219232	DEPATT_00219232	DEPATT_00219232	DHFs	DEPATT_PROD003
DEPATT_00219233	DEPATT_00219233	DEPATT_00219233	DEPATT_00219233	DHFs	DEPATT_PROD003
DEPATT_00219234	DEPATT_00219234	DEPATT_00219234	DEPATT_00219234	DHFs	DEPATT_PROD003
DEPATT_00219235	DEPATT_00219235	DEPATT_00219235	DEPATT_00219235	DHFs	DEPATT_PROD003
DEPATT_00219236	DEPATT_00219236	DEPATT_00219236	DEPATT_00219236	DHFs	DEPATT_PROD003
DEPATT_00219237	DEPATT_00219237	DEPATT_00219237	DEPATT_00219237	DHFs	DEPATT_PROD003
DEPATT_00219238	DEPATT_00219238	DEPATT_00219238	DEPATT_00219238	DHFs	DEPATT_PROD003
DEPATT_00219239	DEPATT_00219239	DEPATT_00219239	DEPATT_00219239	DHFs	DEPATT_PROD003
DEPATT_00219240	DEPATT_00219240	DEPATT_00219240	DEPATT_00219240	DHFs	DEPATT_PROD003
DEPATT_00219241	DEPATT_00219241	DEPATT_00219241	DEPATT_00219241	DHFs	DEPATT_PROD003
DEPATT_00219242	DEPATT_00219242	DEPATT_00219242	DEPATT_00219242	DHFs	DEPATT_PROD003
DEPATT_00219243	DEPATT_00219243	DEPATT_00219243	DEPATT_00219243	DHFs	DEPATT_PROD003
DEPATT_00219244	DEPATT_00219244	DEPATT_00219244	DEPATT_00219244	DHFs	DEPATT_PROD003
DEPATT_00219245	DEPATT_00219245	DEPATT_00219245	DEPATT_00219245	DHFs	DEPATT_PROD003
DEPATT_00219246	DEPATT_00219246	DEPATT_00219246	DEPATT_00219246	DHFs	DEPATT_PROD003
DEPATT_00219247	DEPATT_00219247	DEPATT_00219247	DEPATT_00219247	DHFs	DEPATT_PROD003
DEPATT_00219248	DEPATT_00219248	DEPATT_00219248	DEPATT_00219248	DHFs	DEPATT_PROD003
DEPATT_00219249	DEPATT_00219249	DEPATT_00219249	DEPATT_00219249	DHFs	DEPATT_PROD003
DEPATT_00219250	DEPATT_00219250	DEPATT_00219250	DEPATT_00219250	DHFs	DEPATT_PROD003
DEPATT_00219251	DEPATT_00219251	DEPATT_00219251	DEPATT_00219251	DHFs	DEPATT_PROD003
DEPATT_00219252	DEPATT_00219252	DEPATT_00219252	DEPATT_00219252	DHFs	DEPATT_PROD003
DEPATT_00219253	DEPATT_00219253	DEPATT_00219253	DEPATT_00219253	DHFs	DEPATT_PROD003
DEPATT_00219254	DEPATT_00219254	DEPATT_00219254	DEPATT_00219254	DHFs	DEPATT_PROD003
DEPATT_00219255	DEPATT_00219255	DEPATT_00219255	DEPATT_00219255	DHFs	DEPATT_PROD003
DEPATT_00219256	DEPATT_00219257	DEPATT_00219256	DEPATT_00219257	DHFs	DEPATT_PROD003
DEPATT_00219258	DEPATT_00219258	DEPATT_00219258	DEPATT_00219258	DHFs	DEPATT_PROD003
DEPATT_00219259	DEPATT_00219259	DEPATT_00219259	DEPATT_00219259	DHFs	DEPATT_PROD003
DEPATT_00219260	DEPATT_00219263	DEPATT_00219260	DEPATT_00219263	DHFs	DEPATT_PROD003
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EXHIBIT 3

LITERATURE REVIEW

TIBIAL COMPONENT DEBONDING IN TKA

By:

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October 17, 2018

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TIBIAL COMPONENT DEBONDING IN TKA

LITERATURE REVIEW **OCTOBER 17, 2018**

The purpose of the literature review is to discuss the etiologies of peri-prosthetic osteolytic bone resorption below a cemented total knee implant and document evidence of osteolytic processes consistent with early tibial baseplate-cement debonding.

Tibial Component Cement Debonding Failures

Cemented tibial components are intended to be secured to bone via bone cement (polymethylmethacrylate or PMMA).

Historically, aseptic tibial implant loosening at the bone–cement interface was an observed cause of failure with semi-constrained TKR implant designs. Modes of early failure in TKRs include infection, instability, patellofemoral complications, polyethylene wear with secondary osteolysis and aseptic loosening. Of those mechanisms, aseptic loosening was the least common cause (three percent).[1] In the context of joint replacements, osteolysis refers to bone destruction as seen on conventional radiographs and corresponds to bone defects seen during revision surgery.

Although in some early TKA designs, failure of the tibial component was more prevalent, subsequent changes in design and surgical technique have for the most part decreased early aseptic failure rates of the tibial or femoral components. However, there have been reports of early revision of aseptic painful total knees in which the tibial tray is loose or debonded at the implant- PMMA interface[2,3,4,5,6,7] Isolated tibial component debonding from the cement had been sparsely reported in the literature.[8] Ries et al.[9] and Foran et al.[10] each reported on a series of cement debonding involving short-stem Precoated MIS tibial trays. Their patients were revised for early aseptic loosening of the tibial component despite normal initial postoperative radiographs. Intraoperatively, in all cases, more than 50% of the tibial tray was devoid of cement and factory-applied PMMA. The lucency in these cases is not due to stress shielding. **Cement debonding failures require surgical intervention with at least partial revision of components.**

In many of these cases the cement bed is intact. That is, the cement is not cracked and is adherent to the proximal tibial bone.[11] These patients presented early with a painful knee arthroplasty and there is typically some x-ray radiolucency at the implant -cement interface. In some there is also evidence of bone loss or medial collapse, frequently in Varus.

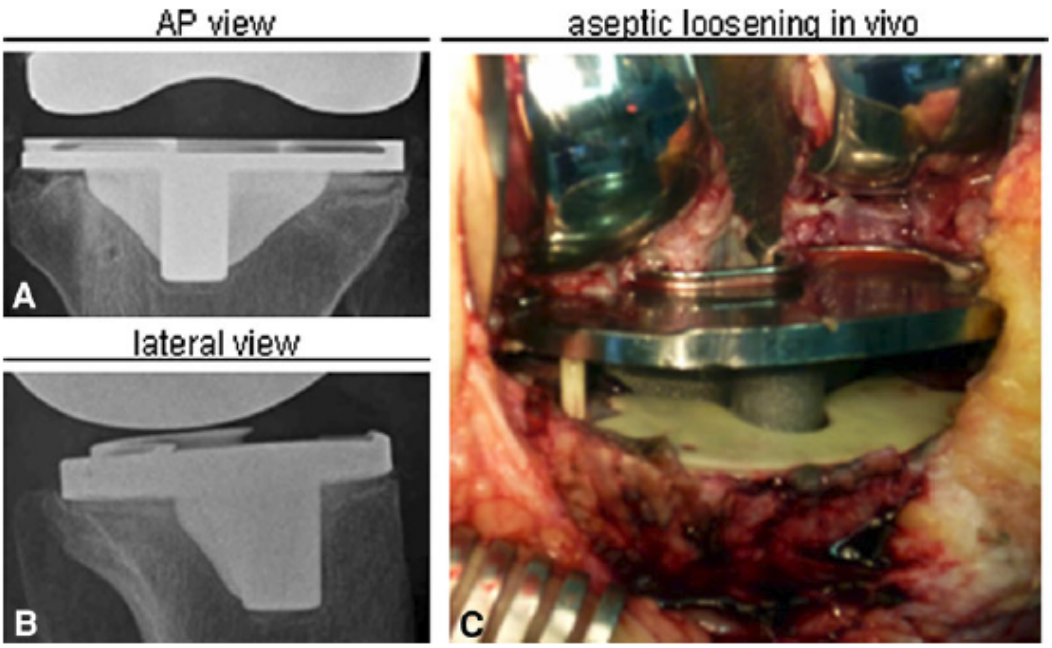


Figure 1: A–C Conventional (A) AP and (B) lateral view radiographs of a short-keeled TKA show apparent radiolucency. (C) Failure at the implant-cement interface was noticed in four of the five revision cases. Note the debonding and remodeling. The tibial tray is a thinner Ti6Al4V alloy and the stem is not long. The lucency in this case is not due to stress shielding. (Reis et al.[12])

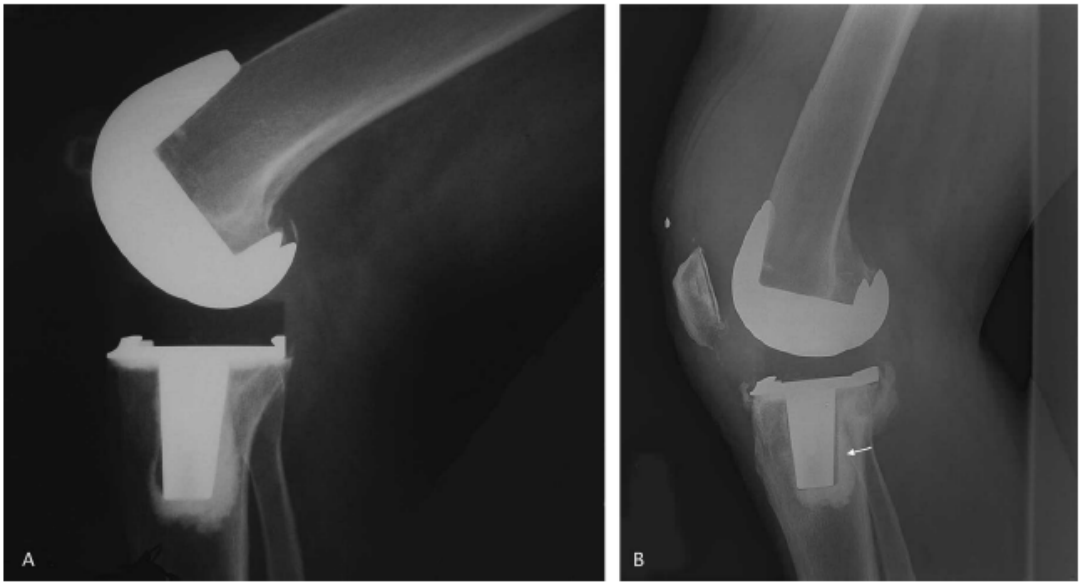


Figure 2: A) The 6-week postoperative radiograph showed good alignment and fixation of the components although a linear defect in the cement mantle was present along the anterior tibial peg. (B) A lateral radiograph obtained 2 years after surgery shows tibial component loosening with debonding between the tibial baseplate and surrounding cement mantle (arrow). The posterior portion of the tray appears to have a defect because of the rotational position of the radiograph. (Cheng et al. [13])

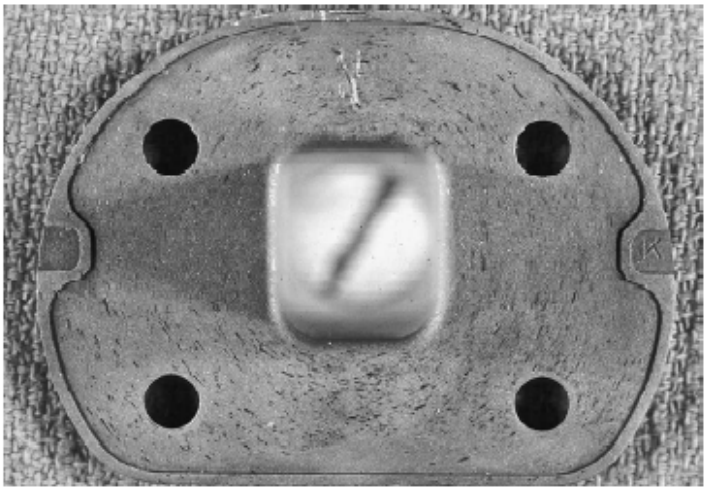


Figure 3: A photograph shows the undersurface of the tibial baseplate. There is a circular pattern of abrasive scratches, indicating the implant debonded and rotated in the cement mantle. (Cheng et al. [14])

Metal and PMMA debris in a TKA may result from debonding and micromotion between the implant and cement.

In a case example, Chen et al. [15] reported a lack of UHMWPE debris with abundant PMMA and metal debris in histologic specimens of the osteolytic membrane indicated that the osteolysis in that case was caused primarily by debris generated at the tibial baseplate-cement interface rather than the bearing surface. (Figures X & Y) The osteolysis developed primarily from PMMA debris.

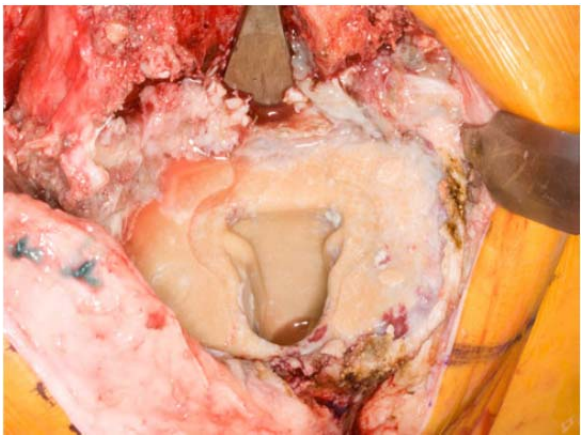


Figure 4: Debonding of the tibial component leaves behind a nearly intact cement mantle attached to the proximal tibia. (Arsoy et al [16])

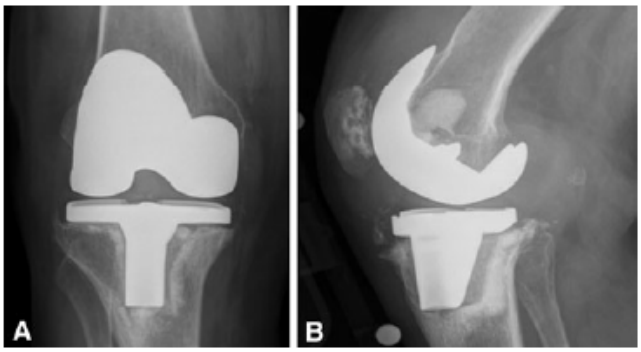


Figure5 A–B: The AP view (A) reveals a pronounced varus position of the tibial tray. The lateral view (B) demonstrates flexion subsidence with debonding at the cement-prosthesis interface. (Arsoy et al [17])

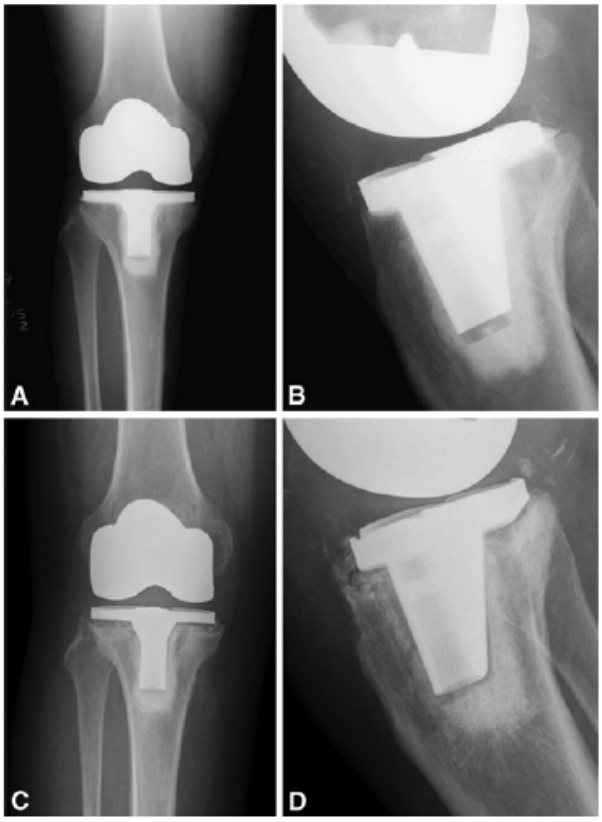


Figure 6 A–D: (A) Anterior and (B) posterior radiographs of a patient with an asymptomatic TKA at 24 month postoperatively. There are radiolucent lines present underneath the tibial tray. (C-D) Nine months later the patient presents with radiographs showing debonding of the tibial component. (Arsoy et al [18])

In a study by Arsoy et al.[19] tibial component debonding accounted for the majority of failures , 25 out of over 1300 primary NexGen LPS TKAs implanted with a 3- fluted tray at the Mayo Clinic between 2001and 2012. (1.9%).

In those patients who required revision for tibial debonding, the prerevision radiographs shared characteristic findings: debonding of the tibial component at the prosthesis-cement interface and subsidence of the tibial component into varus and into flexion (**Figure 5**). In some cases, radiographic documentation of debonding was present before subsequent subsidence into varus and flexion **(Figure 6**). In all cases, intraoperative findings revealed a grossly loose tibial component with most of the cement mantle still attached to the bone. No case exhibited signs of macroscopic polyethylene wear. Osteolysis involving the posterior femoral condyles was apparent in some cases and was attributed to cement debris.

Two studies, Hazelwood et al.[20] and Kopinski et al.[21] have implicated newer high viscosity cement as a potential cause for tibial implant debonding. (DePuy HVC and Cobalt HVC, Smartset HV, Smartset –HVG and Palacos R). Of the 13 Vanguard TKAs undergoing revision in the series by Kopinski et al.[22], 8 were cruciate-retaining and 5 were posterior-stabilized design. At the time of revision, all patients had a grossly loose tibial component that could easily be lifted off of the cement mantle during intraoperative assessment.

In the Kopinski et al.[23]series revisions were completed for pain prior to definitive development of radiolucent lines or osteolysis. Prerevision radiographs demonstrated the absence of radiolucent lines in 11 of 13 anteroposterior knee radiographs. One patient demonstrated a radiolucent line just medial to the keel of the tibial component and one patient demonstrated a complete, radiolucent line across the entire surface of the tibial component. Ten of 13 patients demonstrated the absence of radiolucent lines of the tibial component on the lateral radiograph. Three patients demonstrated a radiolucent line anterior to the keel of the tibial component on the lateral radiograph. Six patients received a nuclear imaging bone scan to evaluate for component loosening or infection, with all results being negative for definitive signs

of component loosening. Twelve had cemented femoral components with 4 demonstrating debonding at the implant cement interface and 2 demonstrating loosening at the bone cement interface.

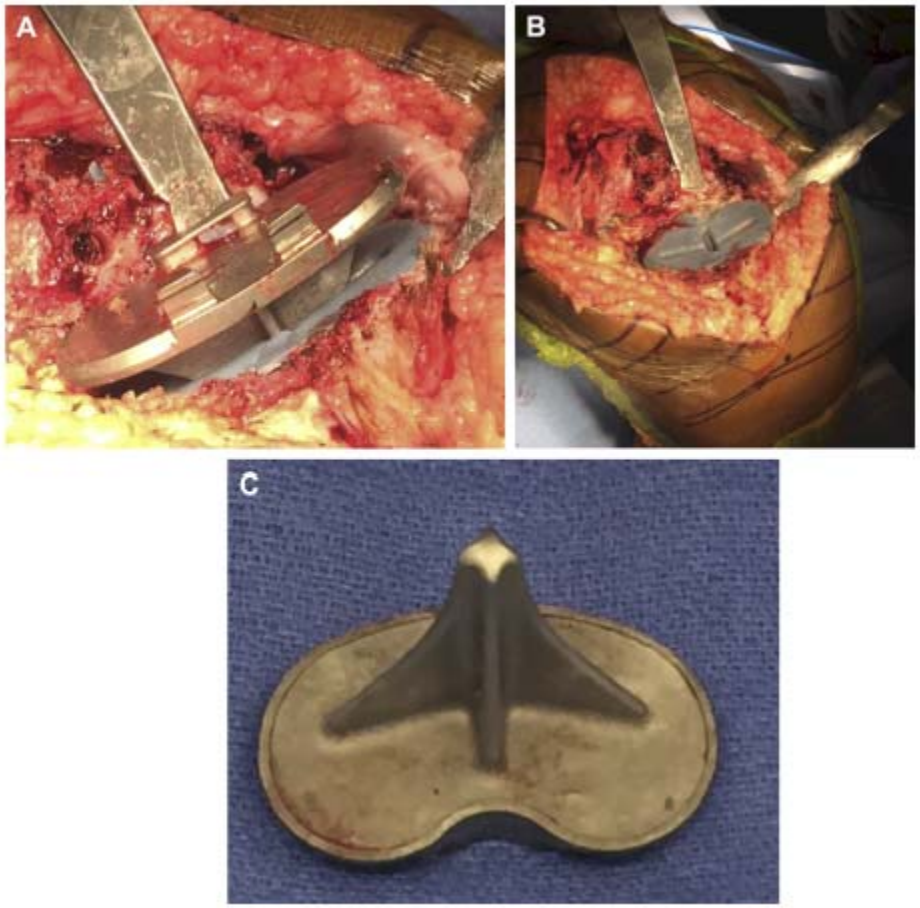


Figure 7: . (A) Tibial baseplate being elevated off of the tibial surface and the cobalt cement mantle. (B). Intraoperative image of the proximal tibia with the remaining intact cobalt cement-bone interface. (C) Extracted tibial baseplate at the time of revision surgery. The component demonstrates no adherence of cement to undersurface of the tray. (Kopinski et al.[24])

Results with high viscosity cement apparently vary with surgeon groups. Crawford et al.[25] (*the Vanguard system surgeon-designers*) utilized the Vanguard TKAs as did Kopinski et al.[26] At a mean 5.4 years follow-up, only 1 in 1851 knees in obese patients had aseptic loosening of the tibial component for an incidence of 0.054%.

Hazelwood et al.[27] reported on a case series of eleven patients implanted between 2005 and 2010 with an uncommon cause of TKR failure secondary to aseptic loosening due to cement–implant interface failure and de-bonding (0.36%). The report is consistent with other previous reports of early TKR failure due to cement-implant fixation failure.

- After mixing, soft HVC was independently applied evenly to dry implant surfaces and finger packed into dried open metaphyseal bone surfaces.

- All symptomatic patients presented similarly to the office or emergency room with a new onset of knee pain after an initial pain-free interval following their TKR surgery.
- The average time between the index procedure and the onset of new knee pain was 23 months (range, 2–67 months).
- On physical examination each patient was noted to have a trace to moderate effusion prior to revision surgery.
- Patients initially developed some relative radiolucency adjacent to the cement– bone interface in the proximal tibia, often without clear evidence of cement–implant radiolucency.
- As symptoms continued radiolucency at the cement–implant interface developed.
- In two cases there was loosening and varus subsidence of the tibial implant.
- In eight of nine cases, knee pain preceded radiographic evidence of loosening with radiographic changes appearing on average 6.7 months after the onset of pain (range 1 to 22 months).
- In one failure there was subsidence of the tibial tray two months prior to the onset of pain.
- There were no radiographic signs of loosening observed of the femoral or patellar components in these patients.
- All patients had a sterile TKR joint fluid aspiration performed prior to revision. Revision operative cultures were all negative among the eight of the nine cases cultured during the revision.
- Intraoperative evaluation of the failed nine TKRs revealed gross loosening and fixation failure of the tibial implant-cement interface in all cases.
- In all cases there was observed nearly complete absence of cement adherence to the tibial tray at the time of implant removal.
- The cement–bone interface was observed to be intact except for the two cases in which there was tibial implant varus subsidence.

Four of the nine failed TKRs had isolated loosening of tibial implant only at the time of revision surgery. The remaining five had additional loosening of either the femoral implant, patellar implant, or both at the time of revision. In these cases, the patellar and femoral components were similarly found to be almost completely devoid of adherent cement. These observed findings are all consistent with failure of fixation or de-bonding at the cement–implant interface. AP alignment was initially appropriate patients as confirmed by standing long x-rays.

Registry-based studies have reported an increased risk of aseptic tibial loosening for the cemented Low Contact Stress (LCS) total knee replacement compared with other cemented designs. Kutzner et al.[28] studied 32 failed LCS complete cases. All implants had a rotating platform with a non-posterior stabilized mobile bearing insert. Loosening of the tibial baseplate was the reason for revision in 25 retrievals, occurring at the implant-cement interface in 16 cases. Polishing was observed on the lower surface of the baseplate and correlated to the level of cobalt, chromium, and zirconium in the blood. No evidence of abnormally high polyethylene wear was present. Full cementing was observed in 3 cases and only proximal surface cementing in the balance. Abrasive and corrosive damage occurs on the CoCr tibial baseplate following cement debonding in vivo. It has also been identified on CoCr femoral implants.[29]

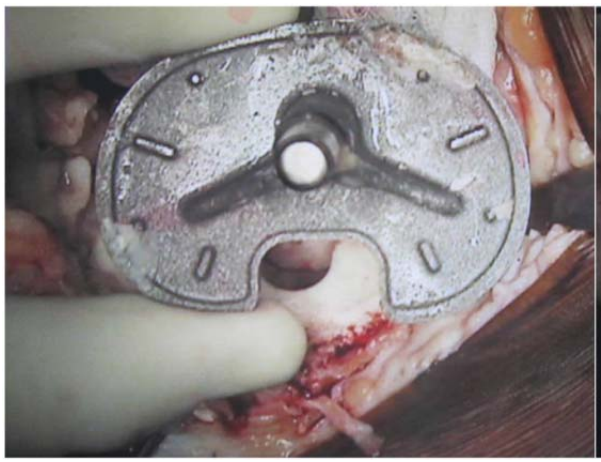


Figure 8: Cement–implant interface. This photograph was taken at the time of revision surgery demonstrating the complete absence of cement on the tibial tray. The tibial tray was grossly loose at the time of revision and easily removed.(Hazelwood et al.[30])

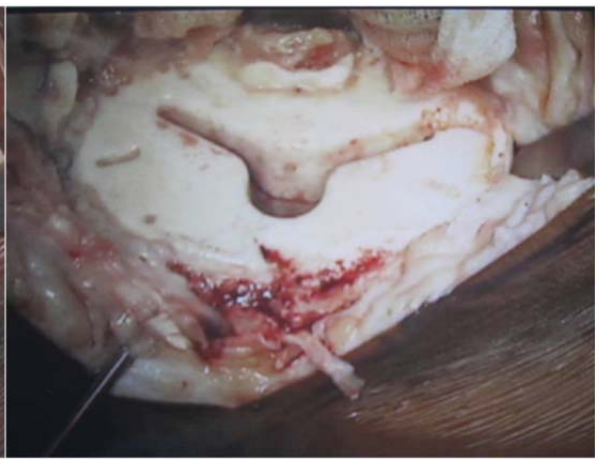


Figure 9: Cement–bone interface. Intraoperative photo taken at the time of revision demonstrating an intact cement–bone interface of the proximal tibia. (Hazelwood et al.[31])

The authors found:

- For each 1 mm increase in cement thickness the odds of failure due to aseptic loosening decreased by 61%.
- Greater varus alignment was associated with a shorter time to failure.
- The roughness, Ra, of a new LCS baseplate's lower surface was 3.7 (SD 0.7) µm. for comparison, a matte finish from grit blasting has a roughness of about 1 to 2.5 µm. An aggressive grit blast or a plasma spray sintering surface has a Ra between about 2.5 and 12.5 µm. Greater roughness can be achieve by texturing via machining, casting, forging.[32] In general, metal-cement interface strength increases with increasing surface roughness and that common surface treatments such as AlO_2 grit–blasting (Ra = 6.76 µm) produce interface strengths similar to plasma spray porous coated specimens.[33] Other porous coatings generate higher interface strengths.[34,35]
- Debonding of the tibial component at the implant-cement interface was the predominant cause of tibial aseptic loosening.

In the work of Kutzner et al.[36] damage features were correlated to loosening locations. Implant–cement loosening was classified if the lower tibial surface was clearly polished, and a radiolucent line could be seen between implant and cement was visible on the pre-revision radiographs. Cement–bone loosening was classified if the bone cement mantle was firmly attached to the retrieved implant, or if radiolucent lines between cement mantle and bone were visible. A mixed failure was classified if both implant– cement and cement–bone loosening were present. From the cases of tibial loosening confirmed by retrieval analysis, 12 LCS tibial baseplates loosened at the implant–cement interface and only 3 at the bone–cement interface. In 4 retrievals polishing of the lower baseplate surface was observed along with radiolucent zones at the cement–bone interface indicating a mixed failure mode. In 3 cases the failure site could not be determined due to insufficient information.

PMMA Characteristics[37]

The manufacturer of bone cements supplies hospitals with PMMA polymer powder in primary packaging and monomer liquid in an ampule as a so-called "two component system." The main ingredient of the liquid is the monomer MMA. The cement powder component itself comprises a spherical polymer powder made of PMMA or MMA copolymers containing the initiator dibenzoyl peroxide (BPO) required for initiating the cement curing. The powder also contains a radiopacifier, either zirconium dioxide or barium sulfate, required for the cement visibility in radiographs. Optionally an antibiotic or a dye for coloring of the powder may be present. Radiopacifier, antibiotics, and dye do not take part in the curing process.

The viscosity of bone cements at the dough stage is determined mainly by the chemical composition and the powder to monomer ratio. These aspects should never be modified in the operating theater to modify the viscosity. There is one method to modify the viscosity without changing other characteristics of the cement, however, and that is the prechilling of the cement. The velocity of the reaction, and with it the viscosity, depends on the temperature. Prechilling of cements, especially of high viscosity cements, has been introduced with the introduction of mixing systems to make mixing of cement in these systems more convenient and to improve the quality of the mixture, especially with respect to porosity. Bone cements usually are divided into two categories: high and low viscosity cements. High viscosity bone cements have short wetting phases and lose their stickiness quickly. During the working phase the viscosity remains unchanged and slowly increases toward the end of this phase. Generally the working phase is especially long. Low viscosity bone cements have a long lasting liquid to low viscosity wetting phase. The material usually remains sticky for 3 minutes or longer. In its working phase the viscosity quickly increases. A late application at a too high viscosity level may result in poor interfaces between the prosthesis, the cement, and the bone.

A higher viscosity cement has different handling characteristics and different times for optimal mixing, hardening and working life for application to the implant and bone. If the mixed PMMA is to applied to the implant at the optimal time the strength of the adhesion can be compromised. Among other factors, it is well known that a relatively narrow range of molecular weights need to be maintained between batches of PMMA powder in order to assure reproducible and repeatable hardening parameters. Kutzner et al.[38] used the same implant s with a lower viscosity cement for several years without any debonding incidents , and experienced 13 of these unusual debonding failures after switching to a higher viscosity cement. Variations in the PMMA monomer powder molecular weight, particle size and shape may alter the cure time and adhesion properties. The different properties and/or the repeatability (quality control) of the newer higher viscosity cements may have played a role in these debonding incidents.

Mechanical debonding results from shear and torsion, and tensile lift-off forces. Implant geometry, surface finish, cement properties and variation in cement application protocols determine the strength of the cement- tibial implant interface. Hydrolytic failure of the cement–metal interface is thought to be one initiating factor in aseptic loosening of cemented orthopaedic implants. This behavior is a result of a hydrolytic weakening of the adhesive metal–polymer bond. Among the many factors influencing the long-term stability of cemented hip prostheses, the interface between the implant and bone cement is considered to be one of the most susceptible to failure. Osteolysis and loosening of the implant can occur by the interaction of mechanically and/or hydrolytically induced bond failure of the metal-cement interface.[39]

Some companies provide training information concerning cementing technique. For example, in 2015 Dough Dennis MD co-authored a white paper with a DePuy research fellow, Rick Kowalski, where he shared fundamental principles to bone preparation and application of cement to minimize the potential of earl knee implant loosening including practices around bone preparation and washing, cement pressurization, cement application and minimizing movement before cement has cured. [A] Bone cement technique historically to emphasized holding cemented in place without moving the limb until the cement had sufficient time to cure. In some practices it has become commonplace to cement both the femur and the tibia simultaneously, moving the knee immediately after cementation, and then holding the components in place. This motion is thought by some to reduce or prevent cement adherence to the tibial base plate due to contamination . In a recent American Academy of Orthopaedic Surgeons (AAOS) Scientific Exhibit , entitled " Simultaneous Femoral and Tibial Cementation Negatively Effects Tibial Fixation in Total Knee Arthroplasty", Mason et al documented flow of lipids under the tibial implant that migrated (potentially) in the cement-implant interface with applied motion.

Debonding

PMMA is strongest in compression and weakest in tension and shear. PMMA does not bond well to metal (or polyethylene) and the implant- bone cement interface is susceptible to hydrolytic breakdown.[40] **It is well known that mechanical interlocks are needed to create a stable implant-PMMA cement interface capable of withstanding in vivo shear and tensile stresses resulting from in vivo loading of the knee**. The ability of bone cement to adhere to the implant surface is also dependent on the surface finish. Implants with a rough surface finish require greater force to disrupt their interface with the cement than do stems with a smooth or polished surface.[41] Precoating and having a roughened surface proximally and distally on the stem contribute to extended longevity of the cement-metal interface.[42] However, if micromotion occurs at the cement-metal interface, the fretting of a smoother surface implant results in less cement and metallic abrasion than an implant with a rough surface finish.[43]

During a TKA procedure the hard or even sclerotic proximal tibial sub-articular cortical bone is removed and replaced with a tibial implant. The tibial implant is most commonly a modular assembly of a polyethylene liner supported by a metallic tray.[B] The implant is most frequently (*and historically most successfully*) secured with a centralized stem protruding into the remaining and substantially weaker proximal metaphyseal bone. **Various design features have been used by implant manufacturers to increase the implant-PMMA cement interface strength such as pockets with undercuts, surface roughening and soundly attached porous coatings. Some have pre-coated metallic tibial tray implants with a layer of PMMA to assure optimal adherence to metal (Zimmer Precoat). Increased tibial stem geometry in terms of length and use of central keels or ribs or pegs are frequently used to reduce shear and tensile stresses at the implant-cement and cement –bone interfaces due to physiologic loading. Patient matched stress analyses have shown that a tibial base plate with a prophylactic longer stem significantly reduces compressive and shear stresses on the cement-device**

[A] Cement Technique in Total Knee Arthroplasty. DSUS/JRC/1114/0581 06/16 ©DePuy Synthes 2015

[B] Modular tibial implant base-plates (tibial trays) have been manufactured from various Titanium alloys, Oxinium, a Zirconium-Titanium alloy and less frequently, ceramics. Some tibial implants are monolithic (all polyethylene) in construct.

interface and therefore may help to reduce the possibility of tibial loosening in in at-risk patients such as those who are obese and active and frequently place greater loads on their implants.[44]

The tradeoff for reduced overall stress and stability is a redistribution of stresses in the proximal tibial bone. Following TKA, physiologic loading generates an altered stress pattern in the proximal tibia which results in some remodeling or redistribution of bone. The stress patterns are altered by implant ML positioning. Bone adapts to mechanical alterations such as correction of malalignment. Tibial metaphyseal periprosthetic bone is remodeled after TKA due to mechanical axis correction, resulting in more balanced bone stock below the tibial tray.[45]

The stresses on a total knee tibial component are primarily compressive, although shear and torsional stresses also occur. In cementer TKA, tibial component loosening at the cement–bone interface typically develops from subsidence or tilting of the tibial baseplate, particularly if the knee is mal-aligned.[46] Implant subsidence usually is associated with fracture of the cement mantle or loosening at the bone-implant interface.[47]

Debonding Forces, Tilting – fluid entrainment & fluid pressure, forces on the implanted TKA- High tensile forces at the tray-cement result tom AP or ML tilting or rocking due to AP shear and translational motion at the articular interface. PS and ultras congruent implants implant transmit greater stresses to the tray-cement interface. Malrotated implants generate greater torsion at this interface. Natural knee is an offset hinge. Muscles are positioned to and accustomed to generate forces which apply coupled motions. Unlike the Conformis design, most Implants do not all restore these offset hinge geometries such that residual shear and torsion are applied to the articular interfaces which are then, in part, are transferred to the implant –cement and cement -bone interfaces.

Stumbles generate very high AP shear forces (approaching 1124 lb). This was initially documented by Bergmann and his associates at Research associate at the Julius Wolff Institute for Biomechanics and Musculosketetal Regeneration at Charite University in Berlin, Germany who have made their research work available to the public. Refer to https://orthoload.com/

AP liftoff which is known to occur at the articular surface may now occur at the deboned tibial-cement interface.

Tilting & liftoff results in rocking. When this occurs at the debonded tibia implant -cement interface this results in suction and displacement of fluids contributing to the fluid mediated osteolysis. Longer implantation time in situ with this debonding, rocking, tilting and torsion increase due to cement fretting. Increase lucency develops in the distal stem. A windshield wiper effect develops. Note lucencies around the stem distally in Figure2B, 5A & 5B, 6D & 6C.

There are clusters of high failures are with surgeons that put in the Attune stem tight rather than loose fitting (line to line broaching verses)

One surgeon explained that the fulcrum on the Attune is slight posterior that has a cantilever effect of micromotion that causes debonding. With a tight fit, would that ordinarily mean less thickness of a mantle and saw the Norwegian article on the LCS that linked thinner mantel to increased debonding.

Tibial tray debonding results in unintended motion at the interface between the PMMA bone cement and the metallic or polymeric tibial tray. This tibial implant debonding from its cement mantle results in osteolysis , pain and loosening, and that, in many patients this debonding clearly occurs first, followed by fibrosis and osteolysis which progresses to greater osteolysis and collapse.

Debonding allows motion at the tibial implant – PMMA cement interface. This debonding causes in abnormal motion, higher periprosthetic interface fluid pressures, granulomatous tissue formation, pain, a sensation of instability and bone resorption. The mechanical stress of motion stimulates fluid flow, pressure changes, and the growth of synovial lining cells and macrophages in the implant-interface. It also generates wear debris.

- Motion results in rubbing , metal wear , nano-particulate debris , metal corrosion, metal ions, and varying levels of immuogentic reaction to these metal particles and ions (in sufficient concentrations, cytotoxicity/tissue necrosis) In Attune the metal debris and ions are from CoCr.
- Motion results in rubbing , PMMA cement wear, debris and lytic immune reactions to polymer particles (e.g. osteolysis)
- Motion results in fibrous and granuloma tissue at the cement- implant interface (pseudo joints) and
- Motion is loosening which increases local fluid pressure changes within the bone and at the implant –cement and the PMMA cement - bone interface, resulting in bone resorption

Cobalt ions (or other metal ions such as Ti for Ti alloy trays) immune response, including necrosis and other ALTR/lytic changes, especially in higher concentrations.

Etiology of Osteolysis

In the context of joint replacements, osteolysis refers to bone destruction as seen on conventional radiographs and corresponds to bone defects seen during revision surgery.

In patients with an intact cement bed it is likely that debonding played a predominant role in the osteolysis and any subsequent collapse of the bone well below the cement mantle. If the bone immediately below the cement was not strong enough to bear the mechanical loading breakdown of the bone adjacent to the cement or within the cement –bone interface would have occurred.

An intact and cement –bone interface is not consistent with a pure mechanical overload as stability of the cement –bone interface is not at play in the osteolytic mechanism.

Excessive cement –bone interface motion and mechanical overload at this interface can be ruled out as a cause of the osteolytic response identified in these patients.

In patients with fragmented cement and fibrous material and osteolysis adjacent to the cement (cement breakdown and loosening) mechanical overload at the bone interface may occur as a result of inherently deficient (weak) proximal tibial bone or bone weakening due to sub-surface

osteolysis. Thus, X-ray evidence, when available, can help identify whether the loosening preceded the subsidence or vice versa in patients with both cement loosening and tibial debonding. For example, Hazelwood et al.[48], however, had sufficient x-ray follow up to confirmed that the radiolucency (loosening) initiated at the implant –cement interface. Careful review of the patient's medical records, medical imaging and damage modes identifiable on the retrieved explants is typically helpful when determining the etiology of a device failure. Wear patterns on the distal (cement side) of the tibial baseplates in

Absent x-ray or other physical evidence from retrievals such as histologies of the peri-prosthetic tissues or prosthetic damage patterns, one may not be able to identify whether the loosening preceded the subsidence or vice versa in patients with both cement loosening and tibial debonding.

Implant Interfaces

Tissue response around prosthesis results in either formation of a fibrous layer around the implant, ingrowth into fenestrations on implant or direct bone apposition on prosthesis. Long-term implantation results in implant debris being released into surrounding tissue. [49]

The host's biologic response to the forces applied, the strains developed, the fluid pressures induced, the motion at the bone-implant interfaces and the wear debris and byproducts generated from the prosthesis are each critical to implant longevity. Almost 20% of joint replacement implants fail at 15 to 20 years. Sometimes implant wear debris can cause implant failure resulting from bone fracture, infection, or implant fracture/failure; most often, aseptic osteolysis or loosening leads to wear debris.

There are multiple factors which alone or in some combination, can lead to aseptic loosening of a total joint implant. The most commonly cited in the pear reviewed literature are:

- particulate disease
- fluid pressure
- excessive interface motion / mechanical overload
- stress shielding[C]

Osteolysis & wear

Joint replacement surgery is one of the success stories of modern medicine, restoring mobility, diminishing pain and improving the overall quality of life for millions of people. Using modern biocompatible materials, optimal component design, and meticulous surgical technique, survivorship of cemented or cementless joint replacements is approximately 15 years with more than a 90% probability.[50]

Unfortunately, wear of these prostheses at the articular surface over time generates debris, which activates an innate immune response that can ultimately lead to periprosthetic resorption of bone (osteolysis) and failure of the implant. Aseptic loosening of total knee arthroplasty has

[C] Generally a longer -term phenomenon

been thought to be due to particulate debris of the methylmethacrylate used for fixation of the implants,[51,52] or to debris generated from wear of the polyethylene.[53]

Wear is the progressive damage involving material loss of the surface of components as a result of relative motion between the interacting parts[3]. Wear is primarily at the articular surfaces in most well-functioning implants. However metal and/or bone cement debris occurs when an implant component fractures, when metal components contact inappropriately, or when the bone cement debonds or fractures. Wear is a function of use.[54] The design, materials and production processes specified must provide an implant capable of withstanding foreseeable loads.

In addition to the articular surface wear and failing bone cement, sources of debris include:

- Surgical debris, which should be removed prior to closing.[55] Without careful pulsed irrigation and lavage, the debris following total knee arthroplasty is concerning. For example, De Baets et al.[56]collected an average of 134.9 mg (range 73.6-198.0 mg) of debris. The debris contained on average 75.8 mg of bone particles (range 41.2-109.3 mg), 57.2 mg (range 31.2-83.9 mg) of cement particles, and 1.96 mg (range 0-7.2 mg) of metal particles. On average the total amount of debris consisted for 56.5% of bony fragments, 42% cement fragments and 1.5% metal particles. When these particle get between the articular surfaces they accelerate wear (3rd body wear) and cause pitting damage[57] as seen in the Luci explants.

- Motion between the backside of a modular polyethylene component and the metallic tray (unintended bearing surface) results in micromotion leading to polyethylene wear debris. Although modularity affords various options to the orthopedic surgeon, these benefits come at a price. The locking mechanism greatly affects the propensity for wear and should be considered when choosing a knee implant system. Modern (generation II) modular lock mechanisms with full peripheral capture, polished surfaces, low clearance and robust mechanisms to reduce micromotion and prevent lift off of the modular polyethylene insert (e.g. dovetails, screws ,wires) are required to minimize backside wear. [58,59,60,61,] A polished metal tray surface reduces insert wear.[62,63]

The loosening of prosthetic joints in the absence of infection is by far the most common reason for revision surgery and is known as aseptic loosening. While this may be multifactorial in terms of causation, and non-biological factors may contribute significantly in a particular individual, a significant part is undoubtedly played by the generation of wear debris and the cellular reaction to this in the implant bed.[64] The cellular reactions detected in the tissues in cases of aseptic loosening are those of contact sensitization.

The host's biologic response to wear debris is critical to implant longevity. Particulate disease refers to the host's adverse biologic response to wear debris and byproducts generated from the prosthesis. Debris from several materials in sufficient quantities and physicochemical forms, however, can generate an inflammatory cascade resulting in periprosthetic bone destruction (osteolysis), jeopardizing long-term success of the implant.

Current TKA designs (~ late 1990s) have been slightly modified to reduce wear debris by (among other things):

(1) Optimizing implant articular surface congruencies and constraints to match physiologic requirements.
(2) Polishing the metallic modular surface that interfaces with the non-articular polymer component surface
(3) Improving polyethylene properties via improved production and sterilization processing
(4) Improving the resistance to both early and late motion in the tibia component modular interface in fixed bearing designs.

Most fixed bearing modular total knee implant designs of the 1980s and 1990s exhibited significant motion at the non-articular modular interface, and this interface was a source of increased wear debris. However, the overall aseptic loosening failure rate for the total knee designs being installed by the mid to late 1990's was lower than about 3%.[65,66] Historically, different materials and implant designs have been tried in order to reduce wear and generation of macrophage irritating submicron sized particles, or to provide more biocompatible components, but debris-induced osteolysis is still a long-term problem in total knee replacements (TKRs).

Particulate Disease

The generation of wear debris is an inevitable result of normal usage of joint replacements. Wear debris particles stimulate local and systemic biological reactions resulting in chronic inflammation, periprosthetic bone destruction, and eventually, implant loosening, and revision surgery. It has long been known that wear debris (polymeric or metallic), metal ions and wear by-products from implant materials in sufficient quantities and physicochemical forms can generate an inflammatory cascade resulting in periprosthetic bone destruction (osteolysis), jeopardizing long-term success of the implant.[67] Often this has been described as particulate disease. Particulate disease refers to the host's adverse biologic response to wear debris and byproducts generated from the prosthesis. Debris is produced by wear (primary) or by corrosion. Corrosion-chemical oxidation comprising reduction reactions involving electron transport-produces electrochemical degradation. Metallic implant degradation occurs when electrochemical dissolution and mechanical/physical wear are combined (i.e., tribocorrosion).[68,69,70]

The effects of CoCr and Ti alloy debris, organometallic complexes (by-products of corrosion processes) and metal ions have been well documented in the literature.

- CoCr [71,72,73,74,75,76,77,78,79,80,81,82,83,84,85,86,87,88]
- Ti & Ti alloys[89,90,91,92]

In sufficient concentrations, adverse locate tissue reactions (ALTR) including tissue necrosis and pseudotumors have been associated with metal debris.

Retrospective studies on failed implants suggest that peri-prosthetic osteolysis is mediated by activated macrophages. Cytokines are capable of stimulating bone resorbing cells, the osteoclasts. Bone resorption results in further loosening of the prosthesis, changes in stress, frictional wear, release of more wear debris and recruitment of more macrophages. Bone death and proliferation of macrophages, thus appear to be the cause for pain and loosening of prosthesis.[93]

The membrane-like structure that develops at the bone cement interface of an aseptically loosened prosthesis has histological characteristics that are consistent with a foreign body reaction, probably precipitated by fragments of methacrylate or polyethylene wear debris, or both. Other particulate implant materials, such as Teflon and silicone rubber have been shown to induce a similar reaction. Bone appears to be destroyed in concert with the pseudomembranous inflammatory reaction.[94] These particles initiate a chronic granulomatous inflammation with a significant number of activated macrophages and foreign body type of giant cells, all engaged in attempts to get rid of the debris. These features have been found to be invariably associated with peri-prosthetic lysis of bone.

Inflammation is an important step in the early phase of tissue regeneration around an implanted metallic orthopaedic device. However, prolonged inflammation, which can be induced by metallic corrosion products, can lead to aseptic loosening and implant failure.[95]After implantation of orthopaedic devices a wound healing response is initiated. Numerous cases of metallic implant failure have been reported. These cases are often associated with increased corrosion and signs of inflammation, such as increased amounts of inflammatory cells and pro-inflammatory cytokines in peri-prosthetic tissue[96]. Metallic materials and inflammatory activation can have reciprocal effects. Inflammatory cells are known to produce high ROS amounts creating an oxidative environment, which can increase the corrosion rate[97]. Corrosion products can, in turn, activate pro-inflammatory responses[98]. Prolonged inflammation can eventually lead to aseptic loosening and implant failure.[99]

Particulate debris, bacteria, and cell death are well-known activators of macrophages and can trigger further macrophage cell recruitment, phagocytosis, and the release of osteolytic factors.[100]

Macrophages play multiple roles in both inflammation and in maintaining tissue homeostasis. As sentinels of the innate immune system, they are central to the initiation of this inflammatory cascade, characterized by the release of proinflammatory and pro-osteoclastic factors. Similar to the response to pathogens, wear particles elicit a macrophage response, based on the unique properties of the cells belonging to this lineage, including sensing, chemotaxis, phagocytosis, and adaptive stimulation. The biological processes involved are complex, redundant, both local and systemic, and highly adaptive. Cells of the monocyte/macrophage lineage are implicated in this phenomenon, ultimately resulting in differentiation and activation of bone resorbing osteoclasts.[101]

Today, there is a general agreement that the development of periprosthetic osteolysis at the bone –implant interface is highly related to wear debris delivered continuously from an articulating surface of a TJR. Analyses of periprosthetic tissues retrieved during revision of failed TJRs showed that ultra-high molecular weight polyethyelene (UHMWPE) wear debris is the most frequent type of debris around failed hip, knee and shoulder TJRs, whether the implants were cemented or not. Several hundreds of thousands of ultra-high molecular weight polyethylene (UHMWPE)particles may be generated during a single gait cycle, and depending on their size, the periprosthetic tissues are exposed to a huge amount of wear debris Retrieved UHMWPE particles were mainly globular spheroids in shape, ranging from 0.1 to 2.0 µm in size, with a mean 0.5 µm diameter. Noteworthy, 90% of particles are reportedly less than 1 µm. While there is strong evidence the process of osteolysis involves different cell types, including osteoblasts,

fibroblasts, lymphocytes, etc., the inflammatory response to prosthetic wear debris is mostly driven by cells of the monocyte/macrophage lineage. [102]

Proponents of the biological theory of aseptic loosening have in recent years tended to concentrate on the production and distribution of particulate ultra-high-molecular-weight polyethylene (UHMWPE) debris around the potential joint space. However, mechanical loading of cemented implants with the differing elastic moduli of metal stems, polymethylmethacrylate (PMMA) cement and bone can result in relative micromotion, implying the potential for production of metal and PMMA particles from the stem-cement interface by fretting wear.[103]

Due to the improvement made in UHMWPe processing, packaging, crosslinking and stabilization over the last two decades, the wear rates of UHMWPe in TKAs have been dramatically reduced. Early osteolysis due to excessive wear is now rare and is primarily due to mechanical breakage of devices with thin cross sections (sub-optimal designs) many of which were mal-positioned or sub-optimally positioned and highly loaded.

Despite the beneficial fixative properties of acrylic cement (methylene-polymethacrylate) which are important for implantation of joint prostheses, acrylic cement can also cause severe complications related to the wear process. Extraosseous cement granuloma (ECG) is a rare complication of total knee arthroplasty (TKA) and is related to the production of wear particles of acrylic cement. Aggressive granuloma destroys bone stock of the prosthesis and by increasing the volume, can manifest as tumorous mass compressing adjacent structures. In addition to loosening of the prosthesis, ECG can lead to damage of blood vessels and periprosthetic fractures. On X-ray, ECG manifests as osteolytic zone surrounding implant with the presence of tumorous mass in soft tissues.[104]

Fluid Pressure

Unstable implants in bone become surrounded by an osteolytic zone. This is seen around loose screws, for example, but also in prosthetic loosening. Animal studies have shown that osteolytic zones can be induced by fluctuations in fluid pressure or flow, caused by implant instability**.** Fibrohistiocytic membrane commonly found around loose cemented implants are the result of, rather than the cause of, the loosening process.[105]

Aspenberg and van der Vis[106] (1998) documented that a moderate fluid pressure rise leads to bone resorption and granuloma (with macrophages containing bone debris particles) and that micromotion alone also leads to local bone formation but the formation of fibrocartilage in loaded areas.

Skoglund and Aspenberg (2003) documented that the osteolytic effect of hydrostatic fluid pressure is far greater than that of PMMA particles. Polymer articles such as PMMA elicit an osteolytic response, but the osteolytic effects of pressure appear more important.

Fahlgren et al.[107] (2010) have shown that short bursts of high velocity of fluid flow induce osteolytic bone lesions. **This is consistent with a mechanism of bone resorption induced by instability.**

Fahlgren et al.[108] summarized:

"Prosthetic migration appears to require a fibrous tissue at the interface between prosthesis and bone. This will form as a consequence of the lack of initial stability (De Man et al.. 2005, Lioubavina-Hack et al.. 2006). Several animal models have demonstrated that micromotion of implants is associated with local bone resorption and formation of fibrous tissue (Aspenberg and Herbertsson 1996, Perren 2002, Lioubavina- Hack et al.. 2006)."

"Compression of the fibrous interface tissue may also generate fluid pressure and fluid flow, leading to bone loss (Skripitz and Aspenberg 2000, De Man et al.. 2005)."

" It is a generally accepted hypothesis that fluid flow within the bone matrix plays a key role in a strain-sensing mechanism involved in the normal adaptive response of bone (Van der Vis et al.. 1998a, b, Skripitz and Aspenberg 2000, Qin et al.. 2002, Astrand et al. 2003). Bone strain in vivo leads to pressure gradients and fluid flow through osteocyte canaliculi. This is sensed by the osteocytes, which signal to cells at the bone surface to increase bone formation (Cowin 2002, Burger et al.. 2003, Qin et al.. 2003, Tan et al.. 2007)."

"The fluid pressure in the pseudo-joint of a loose hip prosthesis is elevated at rest, and ranges from 3 to 280 mmHg depending on the position (Robertsson et al. 1997). During different mechanical maneuvers in patients with hip prostheses, such as walking and rising from a chair, the pressure can be 155–776 mmHg (Hendrix et al.. 1983). Thus, fluid pressure and flow can also be induced in the absence of microinstability. This could contribute to the formation of osteolytic cavities that can also be observed around ossseointegrated implants (Harris et al.. 1976, Anthony et al.. 1990, Walter et al.. 2004)."

"Pressure-induced bone resorption has been studied in several animal models (Skripitz and Aspenberg 2000, Astrand et al.. 2003)."

"Several animal studies have shown that a certain amplitude of fluid flow or fluid pressure is needed to induce osteoclast activation (Sato et al.. 1998, Qin et al.. 2002). Cells respond both to deformation and to surface strain induced by fluid flow (Skerry 2006). In cell culture, a low pressure is sufficient for osteoclast activation, either via monocyte-derived macrophages or mesenchymal stem cells (Ferrier et al.. 2000, Liu et al.. 2009). In orthodontic tooth movements, osteoclasts are activated by a pressure of between 30 and 390 mmHg (Sato et al.. 1998). In our model, trauma to the tissue adjacent to the bone did not initiate a resorptive response, as long as no pressure (and high-velocity flow) was applied. Obviously, pressure or flow induces a reaction different from the trauma-induced inflammatory reaction and apoptosis, as these can induce osteoclast activation."

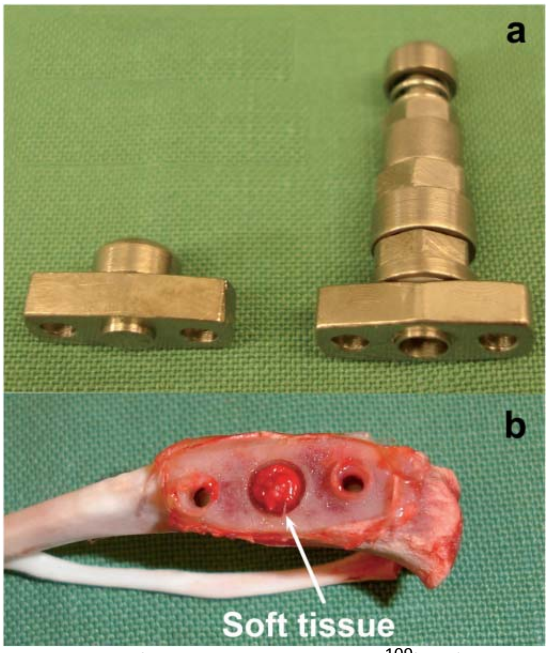


Figure 10 : (From Fahlgren et al.[109]) a) The plate with the central plug (left) and the pressure piston (right) b) tibia showing the bone surface under the titanium plate and the newly formed soft tissue under the pressure piston.

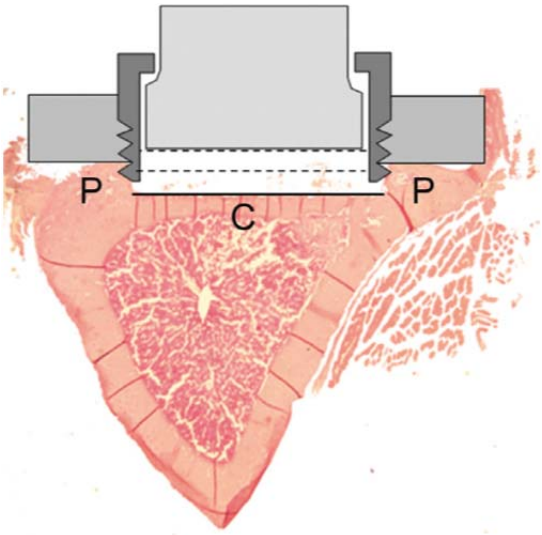


Figure 11 : (From Fahlgren et al.[110]) Transverse section of proximal tibia. The original plug protruded 0.1 mm deeper than the piston (the black line). The lowest position for the piston is 0.6 mm from the bone surface (the middle dotted line). The highest position is 1.4 mm from the bone surface, (the upper dotted line). Thus, a total volume of 8.6 mm3 under the piston, reduced to 4.5 mm3 when the piston is moved to the lower position during a pressure cycle.

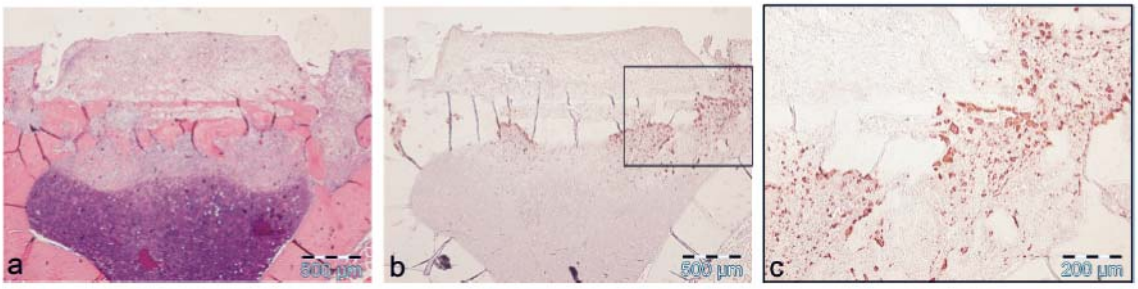


Figure 12: (From Fahlgren et al.[111]) Specimen after 5 days of impact loading with different stainings. a) The soft tissue and the bone plate under the piston seen at 4× magnification (H&E), b) osteoclast activation concentrated under and beside the former piston seen at 4× magnification (immunohistochemistry for CatK), and c) activated osteoclasts within the bone plate seen at 10× magnification (CatK).

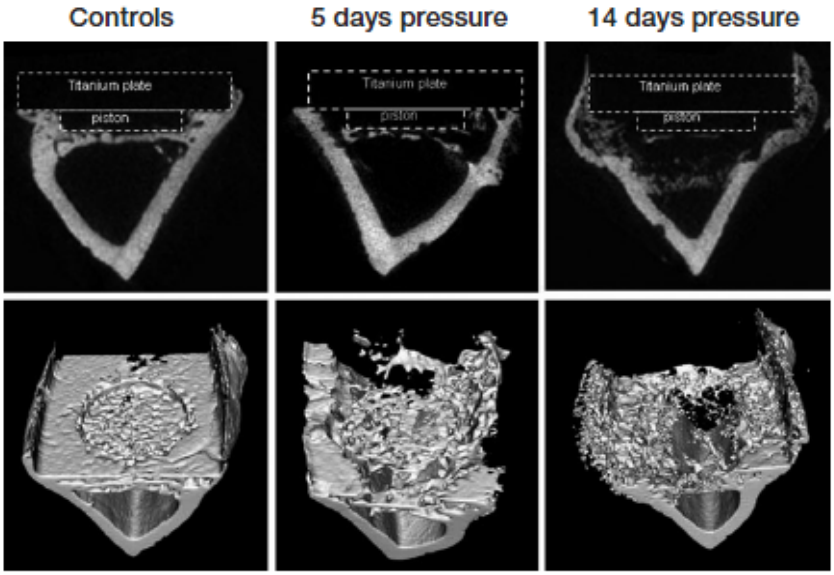


Figure 6. Transverse sections and 3D reconstructions of controls, 5 days pressure and 14 days pressure, showing the osteolytic development.

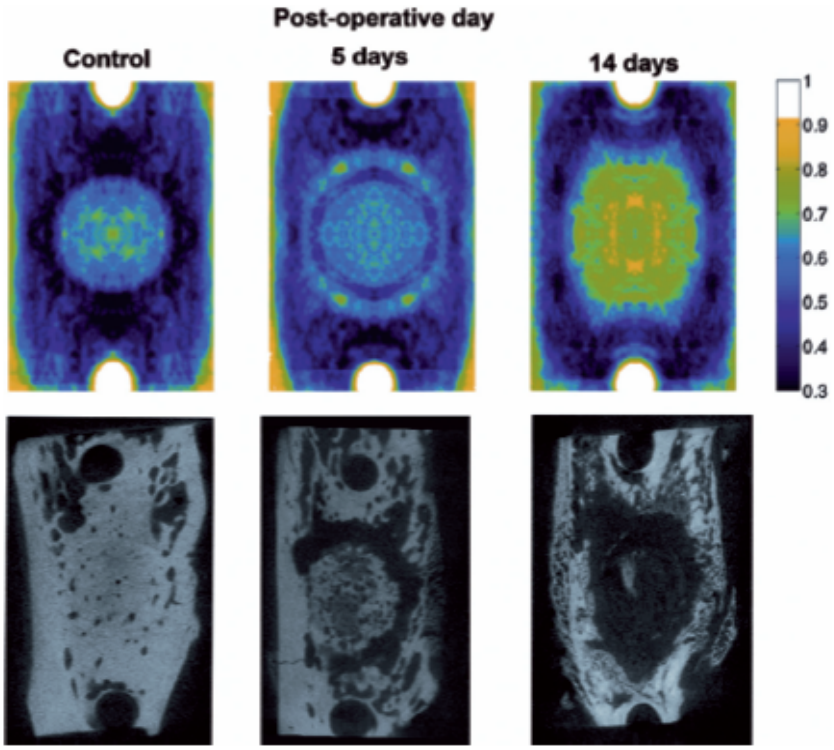


Figure 13: (From Fahlgren et al.[112]) Superimposed microCT scans illustrating the average distribution of the osteolytic response (top). Darkest magenta represents solid bone, cyan, green and yellow represent increasing osteolysis and white represents absence of bone. Typical samples for illustration of specific bone scans below.

Adaptive Bone Remodeling

In a DXA study of 86 TKA patients over 7 years (Jaroma et al. [113] 2016), the mean bone mineral density (BMD) in medial metaphyseal region of interest (ROI) was higher in (preoperatively) varus aligned knees than in valgus knees. It decreased during the first year of the follow-up, thus slightly leveling the difference between the groups. At the 7-year follow-up, the mean medial BMD of the valgus group also decreased compared to baseline, reaching an almost similar decline to that which occurred in the varus group (12% and 13%, respectively). The tibial base plates in this study were each manufactured from a Ti6Al4V alloy.

Varus/valgus mal-alignment of the mechanical axis is reported to transfer up to 100% of the tibio-femoral load through a single compartment.[114] Gait analysis has shown that in normally aligned knees, during walking, approximately 70% of the total load is transmitted through the medial compartment (Hurwitz et al..[115] 1998) causing 2.5-fold load to the medial joint surface compared to the lateral one (Baliunas et al..[116] 2002). Load directions and magnitudes vary with patient size, activity and joint position evaluated. Mündermann et al. [117](2008) (**Figure 14**) measured a 1.1x to 8x differential between medial and lateral compartment loads following total knee arthroplasty. **The peak knee joint load and the flexion angle where the peak load occurs differ substantially among different activities of daily living**.[118]

An increase in bone stress to the medial cancellous bone is related to component migration. Baliunas et al..[119] documented an increase in loading of the medial condyle for those with OA compared to normals. So a decrease in BMD of the more loaded medial condyle post TKA may reflect a more even distribution of bone stress following TKA and a desirable change concerning the survivorship of the prosthesis component.[120]

Asymptomatic local bone resorption of the tibia under the baseplate can occasionally be observed after total knee arthroplasty (TKA). Innocenti et al.[121] studied sixteen cases with local bone resorption were identified. (This study involved Ti6Al4V alloy Genesis II or Profix System tibial trays.) In each, bone loss became apparent at 3 months post-op and did not increase after one year. None of these cases were symptomatic and infection screening was negative for all. An FE analysis demonstrated an influence of baseplate positioning, and also of load sharing, on stresses. The analyses documented that the medial periprosthetic region of the tibia is more sensitive than the lateral region to mediolateral positioning of the baseplate. Medial cortical support of the tibial baseplate is important for normal stress transfer to the underlying bone. The absence of medial cortical support of the tibial baseplate may lead to local bone resorption at the proximal tibia, as a result of the stress shielding effect. The presence of a complete layer of cement reduces stress shielding.[122]

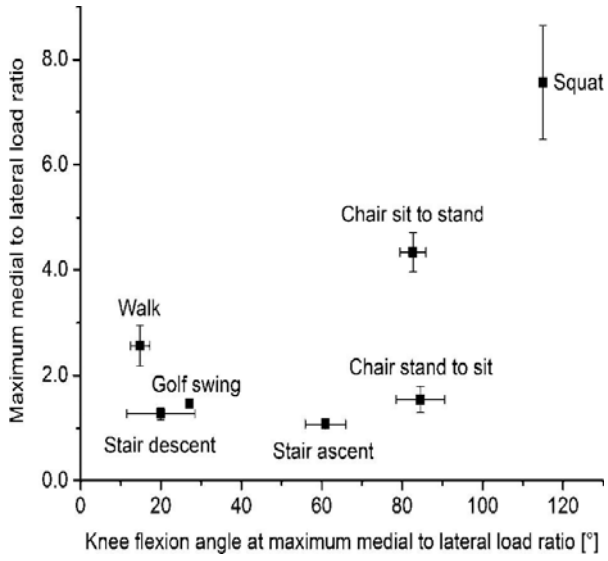


Figure 14: Maximum medial to lateral load ratio for various activities measured in TKA patients. [123]

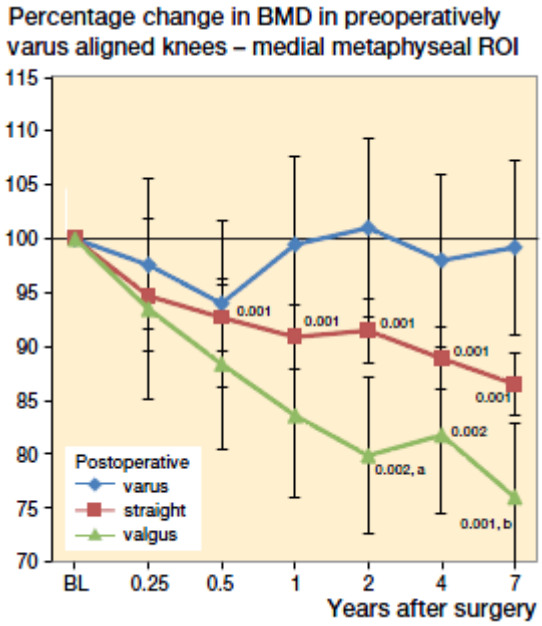


Figure 15: Percentage change and the behavior of bone mineral density (BMD) in the medial tibial region of interest according to the postoperative alignment. 95% confidence intervals are shown. [124]

In the extreme, well-fixed stiff implants with distal stem fixation in the tibia can result in stress shielding and bone loss in the proximal tibia . This is most common in revision TKAs which rely on long distal stems for fixation.

In a study of 50 consecutive patients from each of the 3 implant cohorts (*a DePuy Sigma (Warsaw, IN) all-poly tibial implant, a DePuy Sigma rotating platform CoCr tibial baseplate, or a Zimmer NexGen (Warsaw, IN) fixed bearing Ti tibial baseplate*) Martin et al.[125] (2017) documented that patients with stiffer CoCr trays are associated with significantly more medial tibial bone loss in patients undergoing TKA with a preoperative varus deformity. Ti and all-poly tibial trays were associated with minimal medial tibial bone loss. The authors speculated that the stiff CoCr tray results in a substantial increase in medial tibial stress shielding which resulted in increased medial tibial bone loss in their patient population study. In a few cases patients had substantially more bone loss (range: 1.75-7.89 mm), requiring revision surgery to reinforce and reconstitute the missing bone utilizing bone cement to fill the void. Postoperatively, each patient was noted to have resolution of their medially based symptoms**. It was noted that the patient clinical outcomes did not appear to correlate with the amount of medial tibial bone loss.** In the revisions mentioned, there was no report of loosening, no analysis or report of the histology of the osteolytic region, and no mention of the integrity of the bone cement mantle or the implant- cement interface integrity. Potential contributions of interface motion, fluid fluctuations or particulate debris to the more severe bone loss identified by the authors in the "few cases "mentioned remain uninvestigated/unclear.

In a separate study, Martin et al. [126] documented the remodeling response to 100 posterior stabilized, fixed-bearing total knee arthroplasty where 50 patients had a 4-mm-thick tibial tray

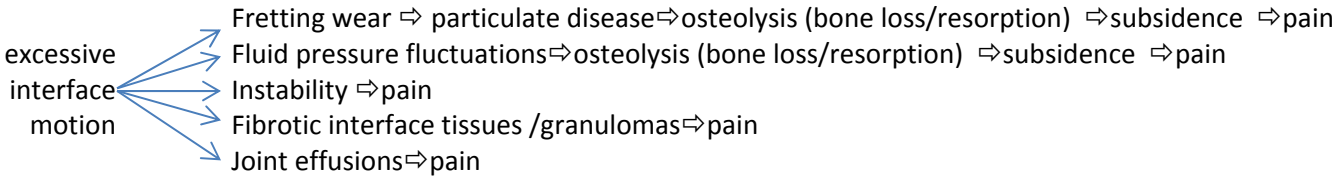
(thick tray cohort, DePuy Attune) and 50 patients had a 2.7- mm-thick tibial tray (thin tray cohort, Stryker Triathlon). All patients underwent a similar preparation of the tibia including cement gun pressurization of the tibial cement mantle and use of Stryker Simplex cement in most patients (Kalamazoo, MI).Patients in the thick CoCr tray cohort had a 7.1 times increased risk of medial tibial bone loss when compared with patients in the thin tray cohort. In addition, the average bone loss of the entire cohort of thick tray patients was significantly greater than that of the thin tray cohort. The cohorts were unmatched consecutive series which allowed the BMI to be higher in the thick tray cohort. Increasing BMI has been associated with increased rates of aseptic tibial debonding. It is possible that in obese patients, as they develop medial tibial bone loss, they may eventually loosen the tibial tray secondary to decreased fixation area of the tibia. [127]

Although the authors speculated that the thicker and stiffer CoCr Attune tibial tray may be the predominant source of medial tibial stress shielding, other implant geometry, placement and alignment differences are potential factors. The tibial base plate designs are substantially different potentially leading to different stress distributions in the proximal tibia. In addition, bone density was not empirically quantified in this study as it was in Jaroma et al. [128]. **The authors stated that both implants perform similarly from a clinical perspective with no notable difference in short term outcomes or complications.**

Discussion and Summary

The host's biologic response to the forces applied, the strains developed, the fluid pressures induced, the motion at the bone-implant interfaces and the wear debris and byproducts generated from the prosthesis are each critical to implant longevity.

Several case studies documented failed TKA due to osteolytic processes which clearly initiated as a result of early tibial baseplate-cement debonding. Interface motion following debonding triggers osteolytic events which eventually cause pain and may progress to significant bone loss and subsidence. Once debonded the predominant mechanisms causing early osteolysis include particulate disease(primarily PMMA induced granuloma) and fluctuations in fluid pressure or flow, caused by implant instability**.** Adaptive bone remodeling is normal and expected following a TKA procedure, and is generally benign. However adaptive bone remodeling, mal-alignment and progressive bone loss often contribute to subsequent bone overload and subsidence.

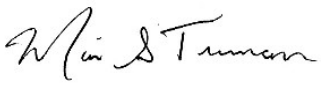


An intact and cement –bone interface is not consistent with a pure mechanical overload as stability of the cement –bone interface is not at play in the osteolytic mechanism. **In cases with intact cement -bone interfaces the early osteolysis is most likely initiated by excessive interface motion as a result of the debonding.**

X-ray evidence, or other physical evidence from retrievals such as histologies of the peri-prosthetic tissues or prosthetic damage patterns, when available, can help identify whether the

loosening preceded the subsidence or vice versa in patients with both cement interface breakdown and loosening and tibial debonding.

Careful review of the patient's medical records, medical imaging and damage modes identifiable on the retrieved explants is typically helpful when determining the etiology of a device failure.



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References

[1] Fehring TK, Odum S, Griffin WL, Mason JB, Nadaud M. **Early failures in total knee arthroplasty**. *Clin Orthop Relat Res* 2001;392:315–8.

[2] Ries C, Heinichen M, Dietrich F, Jakubowitz E, Sobau C, Heisel C.: **Short-keeled cemented tibial components show an increased risk for aseptic loosening**. *Clin Orthop Relat Res.* 2013 Mar;471(3):1008-13.

[3] Foran JR, Whited BW, Sporer SM**.: Early aseptic loosening with a precoated low-profile tibial component: a case series**. *J Arthroplasty.* 2011 Dec;26(8):1445-50.

[4] Hazelwood KJ, O'Rourke M, Stamos VP, McMillan RD, Beigler D, Robb WJ 3rd.: **Case series report: Early cement-implant interface fixation failure in total knee replacement.** *Knee.* 2015 Oct;22(5):424-8.

[5] Kopinski JE, Aggarwal A, Nunley RM, Barrack RL, Nam D.**Failure at the Tibial Cement-Implant Interface With the Use of High-Viscosity Cement in Total Knee Arthroplasty.** *J Arthroplasty.* 2016 Nov;31(11):2579-2582.

[6] Arsoy D, Pagnano MW, Lewallen DG, Hanssen AD, Sierra RJ.: **Aseptic tibial debonding as a cause of early failure in a modern total knee arthroplasty design.** *Clin Orthop Relat Res.* 2013 Jan;471(1):94-101.

[7] Kutzner I, Hallan G, Høl PJ, Furnes O, Gøthesen Ø, Figved W, Ellison P: **Early aseptic loosening of a mobile-bearing total knee replacement.** *Acta Orthop.* 2018 Feb;89(1):77-83.

[8] Arsoy D, Pagnano MW, Lewallen DG, Hanssen AD, Sierra RJ.: **Aseptic tibial debonding as a cause of early failure in a modern total knee arthroplasty design.** *Clin Orthop Relat Res.* 2013 Jan;471(1):94-101.

[9] Ries C, Heinichen M, Dietrich F, Jakubowitz E, Sobau C, Heisel C.: **Short-keeled cemented tibial components show an increased risk for aseptic loosening**. *Clin Orthop Relat Res.* 2013 Mar;471(3):1008-13.

[10] Foran JR, Whited BW, Sporer SM**.: Early aseptic loosening with a precoated low-profile tibial component: a case series**. *J Arthroplasty.* 2011 Dec;26(8):1445-50.

[11] Cheng K, Pruitt L, Zaloudek C, Ries MD.: **Osteolysis caused by tibial component debonding in total knee arthroplasty**. *Clin Orthop Relat Res.* 2006 Feb;443:333-6.

[12] Ries C, Heinichen M, Dietrich F, Jakubowitz E, Sobau C, Heisel C.: **Short-keeled cemented tibial components show an increased risk for aseptic loosening**. *Clin Orthop Relat Res.* 2013 Mar;471(3):1008-13.

[13] Cheng K, Pruitt L, Zaloudek C, Ries MD.: **Osteolysis caused by tibial component debonding in total knee arthroplasty**. *Clin Orthop Relat Res.* 2006 Feb;443:333-6.

[14] Cheng K, Pruitt L, Zaloudek C, Ries MD.: **Osteolysis caused by tibial component debonding in total knee arthroplasty**. *Clin Orthop Relat Res.* 2006 Feb;443:333-6.

[15] Cheng K, Pruitt L, Zaloudek C, Ries MD.: **Osteolysis caused by tibial component debonding in total knee arthroplasty**. *Clin Orthop Relat Res.* 2006 Feb;443:333-6.

[16] Arsoy D, Pagnano MW, Lewallen DG, Hanssen AD, Sierra RJ.: **Aseptic tibial debonding as a cause of early failure in a modern total knee arthroplasty design.** *Clin Orthop Relat Res.* 2013 Jan;471(1):94-101.

[17] Arsoy D, Pagnano MW, Lewallen DG, Hanssen AD, Sierra RJ.: **Aseptic tibial debonding as a cause of early failure in a modern total knee arthroplasty design.** *Clin Orthop Relat Res.* 2013 Jan;471(1):94-101.

[18] Arsoy D, Pagnano MW, Lewallen DG, Hanssen AD, Sierra RJ.: **Aseptic tibial debonding as a cause of early failure in a modern total knee arthroplasty design.** *Clin Orthop Relat Res.* 2013 Jan;471(1):94-101.

[19] Arsoy D, Pagnano MW, Lewallen DG, Hanssen AD, Sierra RJ.: **Aseptic tibial debonding as a cause of early failure in a modern total knee arthroplasty design.** *Clin Orthop Relat Res.* 2013 Jan;471(1):94-101.

[20] Hazelwood KJ, O'Rourke M, Stamos VP, McMillan RD, Beigler D, Robb WJ 3rd.: **Case series report: Early cement-implant interface fixation failure in total knee replacement.** *Knee.* 2015 Oct;22(5):424-8.

[21] Kopinski JE, Aggarwal A, Nunley RM, Barrack RL, Nam D.**Failure at the Tibial Cement-Implant Interface With the Use of High-Viscosity Cement in Total Knee Arthroplasty.** *J Arthroplasty.* 2016 Nov;31(11):2579-2582.

[22] Kopinski JE, Aggarwal A, Nunley RM, Barrack RL, Nam D.**Failure at the Tibial Cement-Implant Interface With the Use of High-Viscosity Cement in Total Knee Arthroplasty.** *J Arthroplasty.* 2016 Nov;31(11):2579-2582.

[23] Kopinski JE, Aggarwal A, Nunley RM, Barrack RL, Nam D.**Failure at the Tibial Cement-Implant Interface With the Use of High-Viscosity Cement in Total Knee Arthroplasty.** *J Arthroplasty.* 2016 Nov;31(11):2579-2582.

[24] Kopinski JE, Aggarwal A, Nunley RM, Barrack RL, Nam D.**Failure at the Tibial Cement-Implant Interface With the Use of High-Viscosity Cement in Total Knee Arthroplasty.** *J Arthroplasty.* 2016 Nov;31(11):2579-2582.

[25] Crawford DA, Berend KR, Nam D, Barrack RL, Adams JB, Lombardi AV Jr.: **Low Rates of Aseptic Tibial Loosening in Obese Patients With Use of High-Viscosity Cement and Standard Tibial Tray: 2-Year Minimum Follow-Up.** *J Arthroplasty.* 2017 Sep;32(9S):S183-S186. doi: 10.1016/j.arth.2017.04.018. Epub 2017 Apr 22.

[26] Kopinski JE, Aggarwal A, Nunley RM, Barrack RL, Nam D.**Failure at the Tibial Cement-Implant Interface With the Use of High-Viscosity Cement in Total Knee Arthroplasty.** *J Arthroplasty.* 2016 Nov;31(11):2579-2582.

[27] Hazelwood KJ, O'Rourke M, Stamos VP, McMillan RD, Beigler D, Robb WJ 3rd.: **Case series report: Early cement-implant interface fixation failure in total knee replacement.** *Knee.* 2015 Oct;22(5):424-8.

[28] Kutzner I, Hallan G, Høl PJ, Furnes O, Gøthesen Ø, Figved W, Ellison P: **Early aseptic loosening of a mobile-bearing total knee replacement.** *Acta Orthop.* 2018 Feb;89(1):77-83

[29] Arnholt CM, MacDonald DW, Malkani AL, Klein GR, Rimnac CM, Kurtz SM: **Implant Research Center Writing Committee, Kocagoz SB, Gilbert JL. Corrosion Damage and Wear Mechanisms in Long-Term Retrieved CoCr Femoral Components for Total Knee Arthroplasty**. *J Arthroplasty.* 2016 Dec;31(12):2900-2906.

[30] Hazelwood KJ, O'Rourke M, Stamos VP, McMillan RD, Beigler D, Robb WJ 3rd.: **Case series report: Early cement-implant interface fixation failure in total knee replacement.** *Knee.* 2015 Oct;22(5):424-8.

[31] Hazelwood KJ, O'Rourke M, Stamos VP, McMillan RD, Beigler D, Robb WJ 3rd.: **Case series report: Early cement-implant interface fixation failure in total knee replacement.** *Knee.* 2015 Oct;22(5):424-8.

[32] Beksac B, Taveras NA, Valle AG, Salvati EA.: **Surface finish mechanics explain different clinical survivorship of cemented femoral stems for total hip arthroplasty.** *J Long Term Eff Med Implants.* 2006;16(6):407-22.

[33] Pittman GT, Peters CL, Hines JL, Bachus KN.: **Mechanical bond strength of the cement-tibial component interface in total knee arthroplasty.** *J Arthroplasty*. 2006 Sep;21(6):883-8.

[34] Davies JP, Harris WH.: **Strength of cement-metal interfaces in fatigue: comparison of smooth, porous and precoated specimens**. *Clin Mater.* 1993;12(2):121-6.

[35] Manley MT, Stern LS, Gurtowski J.: **The load carrying and fatigue properties of the stem-cement interface with smooth and porous coated femoral components**. *J Biomed Mater Res.* 1985 May-Jun;19(5):563-75.
[36] Kutzner I, Hallan G, Høl PJ, Furnes O, Gøthesen Ø, Figved W, Ellison P: **Early aseptic loosening of a mobile-bearing total knee replacement.** *Acta Orthop.* 2018 Feb;89(1):77-83
[37] Kuehn KD, Ege W, Gopp U.: **Acrylic bone cements: composition and properties.** *Orthop Clin North Am.* 2005 Jan;36(1):17-28, v
[38] Kutzner I, Hallan G, Høl PJ, Furnes O, Gøthesen Ø, Figved W, Ellison P: **Early aseptic loosening of a mobile-bearing total knee replacement.** *Acta Orthop.* 2018 Feb;89(1):77-83
[39] Gbureck U, Grübel S, Thull R, Barralet JE: **Modified PMMA cements for a hydrolysis resistant metal-polymer interface in orthopaedic applications.** *Acta Biomater.* 2005 Nov;1(6):671-6. Epub 2005 Sep 15.
[40] Gbureck U, Grübel S, Thull R, Barralet JE: **Modified PMMA cements for a hydrolysis resistant metal-polymer interface in orthopaedic applications.** *Acta Biomater.* 2005 Nov;1(6):671-6. Epub 2005 Sep 15.
[41] Pittman GT, Peters CL, Hines JL, Bachus KN.: **Mechanical bond strength of the cement-tibial component interface in total knee arthroplasty.** *J Arthroplasty*. 2006 Sep;21(6):883-8.
[42] Harris WH: **Is it advantageous to strengthen the cement-metal interface and use a collar for cemented femoral components of total hip replacements**? *Clin Orthop Relat Res.* 1992 Dec;(285):67-72.
[43] Beksac B, Taveras NA, Valle AG, Salvati EA.: **Surface finish mechanics explain different clinical survivorship of cemented femoral stems for total hip arthroplasty.** *J Long Term Eff Med Implants.* 2006;16(6):407-22.
[44] Gopalakrishnan A, Hedley AK, Kester MA: **Magnitude of cement-device interfacial stresses with and without tibial stemming: impact of BMI**. *J Knee Surg.* 2011 Mar;24(1):3-8.
[45] Jaroma A, Soininvaara T, Kröger H.: **Periprosthetic tibial bone mineral density changes after total knee arthroplasty**. *Acta Orthop.* 2016 Jun;87(3):268-73. doi: 10.3109/17453674.2016.1173982. Epub 2016 Apr 27.
[46] Berend ME, Ritter MA, Meding JB, Faris PM, Keating EM, Redelman R, Faris GW, Davis KE.: **Tibial component failure mechanisms in total knee arthroplasty**. *Clin Orthop Relat Res.* 2004;428: 26–34.
[47] Cheng K, Pruitt L, Zaloudek C, Ries MD.: **Osteolysis caused by tibial component debonding in total knee arthroplasty**. *Clin Orthop Relat Res.* 2006 Feb;443:333-6.
[48] Hazelwood KJ, O'Rourke M, Stamos VP, McMillan RD, Beigler D, Robb WJ 3rd.: **Case series report: Early cement-implant interface fixation failure in total knee replacement.** *Knee.* 2015 Oct;22(5):424-8.
[49] Mohanty M**.: Cellular basis for failure of joint prosthesis***. Biomed Mater Eng.* 1996;6(3):165-72.
[50] **Goodman S**.:Wear particulate and osteolysis. ***Orthop Clin North Am*. 2005 Jan;36(1):41-8, vi**
[51] **Goodman S.:**Wear particulate and osteolysis. ***Orthop Clin North Am*. 2005 Jan;36(1):41-8, vi.**
[52] **Cheng K, Pruitt L, Zaloudek C, Ries MD.:** Osteolysis caused by tibial component debonding in total knee arthroplasty**. *Clin Orthop Relat Res*. 2006 Feb;443:333-6.**
[53] **Santavirta S, Takagi M, Gómez-Barrena E, Nevalainen J, Lassus J, Salo J, Konttinen YT:** Studies of host response to orthopedic implants and biomaterials. ***J Long Term Eff Med Implants.* 1999;9(1-2):67-76.**

[54] Schmalzried TP, Shepherd EF, Dorey FJ, Jackson WO, dela Rosa M, Fa'vae F, McKellop HA, McClung CD, Martell J, Moreland JR, Amstutz HC. : **Wear is a function of use, not time**. *Clin Orthop.* 2000 Dec(381):36-46.

[55] **Niki Y, Matsumoto H, Otani T, Tomatsu T, Toyama Y.:**How much sterile saline should be used for efficient lavage during total knee arthroplasty? Effects of pulse lavage irrigation on removal of bone and cement debris**. *J Arthroplasty.* 2007 Jan;22(1):95-9. Epub 2006 Apr 17.**

[56] **De Baets T, Waelput W, Bellemans J.:** Analysis of third body particles generated during total knee arthroplasty: is metal debris an issue? ***Knee.* 2008 Mar;15(2):95-7. doi: 10.1016/j.knee.2008.01.002. Epub 2008 Feb 5.**

[57]**Crowninshield RD, Wimmer MA, Jacobs JJ, Rosenberg AG.:** Clinical performance of contemporary tibial polyethylene components**. *J Arthroplasty.* 2006 Aug;21(5):754-61**.

[58] Conditt MA, Ismaily SK, Alexander JW, Noble PC.: **Backside wear of modular ultra-high molecular weight polyethylene tibial inserts.** *J Bone Joint Surg Am.* 2004 May;86-A(5):1031-7.

[59] Conditt MA, Thompson MT, Usrey MM, Ismaily SK, Noble PC.: **Backside wear of polyethylene tibial inserts: mechanism and magnitude of material loss.** *J Bone Joint Surg Am*. 2005 Feb;87(2):326-31.

[60] **Jayabalan P, Furman BD, Cottrell JM, Wright TM**. *Backside wear in modern total knee designs.* ***HSS J.* 2007 Feb;3(1):30-4. doi: 10.1007/s11420-006-9033-0.**

[61] **Galvin A, Jennings LM, McEwen HM, Fisher J.:** The influence of tibial tray design on the wear of fixed-bearing total knee replacements**. *Proc Inst Mech Eng H*. 2008 Nov;222(8):1289-93.**

[62] **Berry DJ, Currier JH, Mayor MB, Collier JP.:** Knee wear measured in retrievals: a polished tray reduces insert wear. ***Clin Orthop Relat Res*. 2012 Jul;470(7):1860-8. doi: 10.1007/s11999-012-2248-0.**

[63] **Galvin A, Jennings LM, McEwen HM, Fisher J.:** The influence of tibial tray design on the wear of fixed-bearing total knee replacements**. *Proc Inst Mech Eng H*. 2008 Nov;222(8):1289-93.**

[64]Revell PA.: **The combined role of wear particles, macrophages and lymphocytes in the loosening of total joint prostheses.** *J R Soc Interface*. 2008 Nov 6;5(28):1263-78. doi: 10.1098/rsif.2008.0142. Review.

[65] O'Rourke MR, Callaghan JJ, Goetz DD, Sullivan PM, Johnston RC. Osteolysis associated with a cemented modular posterior-cruciate-substituting total knee design : five to eight-year follow-up**.*J Bone Joint Surg Am*. 2002 Aug;84-A(8):1362-71.**

[66] Lachiewicz PF, Soileau ES. The rates of osteolysis and loosening associated with a modular posterior stabilized knee replacement. Results at five to fourteen years. ***J Bone Joint Surg Am*. 2004 Mar;86-A(3):525-30**.

[67] Goodman S: **Wear particulate and osteolysis.** *Orthop Clin North Am.* 2005 Jan;36(1):41-8, vi.

[68] Hallab NJ: **Biologic Responses to Orthopedic Implants: Innate and Adaptive Immune Responses to Implant Debris**. *Spine* (Phila Pa 1976). 2016 Apr;41 Suppl 7:S30-1.

[69] Shearwood-Porter N, Browne M, Milton JA, Cooper MJ, Palmer MR, Latham JM, Wood RJK, Cook RB.: **Damage mechanisms at the cement-implant interface of polished cemented femoral stems.** *J Biomed Mater Res B Appl Biomater.* 2017 Oct;105(7):2027-2033.

[70] Arnholt CM, MacDonald DW, Malkani AL, Klein GR, Rimnac CM, Kurtz SM: **Implant Research Center Writing Committee, Kocagoz SB, Gilbert JL. Corrosion Damage and Wear Mechanisms in Long-Term Retrieved CoCr Femoral Components for Total Knee Arthroplasty**. *J Arthroplasty.* 2016 Dec;31(12):2900-2906.

[71] Benson MK, Goodwin PG, Brostoff J.: **Metal sensitivity in patients with joint replacement arthroplasties.** *Br Med J.* 1975 Nov 15;4(5993):374-5.

[72] Brown, G., Lockshin M,. Salvati E. Bullough P: **Sensitivity to metal as a possible cause of sterile loosening after cobalt-chromium total hip-replacement arthroplasty**. *J Bone Joint Surg* 59A,Mar 0; 59(2), 164-168, 1977.

[73] Howie DW.: **Tissue response in relation to type of wear particles around failed hip arthroplasties.** *J Arthroplasty.* 1990 Dec;5(4):337-48

[74] Mathiesen EB, Lindgren JU, Blomgren GG, Reinholt FP.: **Corrosion of modular hip prostheses.** *J Bone Joint Surg Br.* 1991 Jul;73(4):569-75.

[75] Wang JY, Tsukayama DT, Wicklund BH, Gustilo RB.: **Inhibition of T and B cell proliferation by titanium, cobalt, and chromium: role of IL-2 and IL-6.** *J Biomed Mater Res*. 1996 Dec;32(4):655-61.

[76] Allen MJ, Myer BJ, Millett PJ, Rushton N.: **The effects of particulate cobalt, chromium and cobalt-chromium alloy on human osteoblast-like cells in vitro.** *J Bone Joint Surg Br.* 1997 May;79(3):475-82.

[77] D. Granchi, E. Cenni, G. Ciapetti et al., "Cell death induced by metal ions: necrosis or apoptosis?" *Journal of Materials Science: Materials in Medicine*, vol. 9, no. 1, pp. 31–37, 1998.

[78] Germain MA, Hatton A, Williams S, Matthews JB, Stone MH, Fisher J, Ingham E : **Comparison of the cytotoxicity of clinically relevant cobalt-chromium and alumina ceramic wear particles in vitro**. *Biomaterials.* 2003 Feb;24(3):469-79.

[79] Fleury C, Petit A, Mwale F, Antoniou J, Zukor DJ, Tabrizian M, Huk OL.:**Effect of cobalt and chromium ions on human MG-63 osteoblasts in vitro: morphology, cytotoxicity, and oxidative stress.** *Biomaterials*. 2006 Jun;27(18):3351-60. Epub 2006 Feb 20.

[80] Kwon YM, Xia Z, Glyn-Jones S, Beard D, Gill HS, Murray DW.: **Dose-dependent cytotoxicity of clinically relevant cobalt nanoparticles and ions on macrophages in vitro.** *Biomed Mater.* 2009 Apr;4(2):025018

[81] Lali, F V; Ibbotson, WJ; Royle, M; Lu, F; Fox, A; Housden, J; Leyland, A; Ellison, P; Collins, S.; Shelton, J C; Hart, A J.: **The role of cobalt ions in hypoxic tissue response to orthopaedic wear debris.** Poster No. 1096 • *ORS 2011 Annual Meeting.*

[82] Fleury C, Petit A, Mwale F, Antoniou J, Zukor DJ, Tabrizian M, Huk OL.:**Effect of cobalt and chromium ions on human MG-63 osteoblasts in vitro: morphology, cytotoxicity, and oxidative stress.** *Biomaterials*. 2006 Jun;27(18):3351-60. Epub 2006 Feb 20.

[83] Potnis PA, Dutta DK, Wood SC.: **Toll-like receptor 4 signaling pathway mediates proinflammatory immune response to cobalt-alloy particles.** *Cell Immunol* 2013;282(1):53.

[84] Samelko L, Caicedo MS, Lim SJ, Della-Valle C, Jacobs J, Hallab NJ: **Cobalt-alloy implant debris induce HIF-1α hypoxia associated responses: a mechanism for metal-specific orthopedic implant failure**. *PLoS One*. 2013 Jun 20;8(6):e67127.

[85] Landgraeber S, Jäger M, Jacobs JJ, Hallab NJ**.: The pathology of orthopedic implant failure is mediated by innate immune system cytokines.** *Mediators Inflamm.* 2014;2014:185150.

[86] Landgraeber S, Jäger M, Jacobs JJ, Hallab NJ**.: The pathology of orthopedic implant failure is mediated by innate immune system cytokines.** *Mediators Inflamm.* 2014;2014:

[87] Huk, O., Catelas,I., Mwale, F.,Antoniou, J., Zukor, D., and Petit, A.: **Induction of Apoptosis and Necrosis by Metal Ions *In Vitro***. *The Journal of Arthroplasty*. Vol. 19 No. 8 Suppl. 3 2004.

[88] Revell PA.: **The combined role of wear particles, macrophages and lymphocytes in the loosening of total joint prostheses**. *J R Soc Interface.* 2008 Nov 6;5(28):1263-78.

[89] Grosse S, Haugland HK, Lilleng P, Ellison P, Hallan G, Høl PJ.: **Wear particles and ions from cemented and uncemented titanium-based hip prostheses-a histological and chemical analysis of retrieval material.** *J Biomed Mater Res B Appl Biomater***.** 2015 Apr;103(3):709-17. doi: 10.1002/jbm.b.33243. Epub 2014 Jul 23.

[90] Tsaryk R, Peters K, Barth S, Unger RE, Scharnweber D, Kirkpatrick CJ.: **The role of oxidative stress in pro-inflammatory activation of human endothelial cells on Ti6Al4V alloy.**

Biomaterials. 2013 Nov;34(33):8075-85. doi: 10.1016/j.biomaterials.2013.07.030. Epub 2013 Jul 25.

[91] Haynes DR, Rogers SD, Hay S, Pearcy MJ, Howie DW.:**The differences in toxicity and release of bone-resorbing mediators induced by titanium and cobalt-chromium-alloy wear particles.** *J Bone Joint Surg Am.* 1993 Jun;75(6):825-34.

[92] Pioletti DP, Takei H, Kwon SY, Wood D, Sung KL: **The cytotoxic effect of titanium particles phagocytosed by osteoblasts**. *J Biomed Mater Res*. 1999 Sep 5;46(3):399-407.

[93] Mohanty M**.: Cellular basis for failure of joint prosthesis***. Biomed Mater Eng.* 1996;6(3):165-72.

[94] Herman JH, Sowder WG, Anderson D, Appel AM, Hopson CN.: **Polymethylmethacrylate-induced release of bone-resorbing factors**. *J Bone Joint Surg Am.* 1989 Dec;71(10):1530-41.

[95] Tsaryk R, Peters K, Barth S, Unger RE, Scharnweber D, Kirkpatrick CJ.: **The role of oxidative stress in pro-inflammatory activation of human endothelial cells on Ti6Al4V alloy.** *Biomaterials.* 2013 Nov;34(33):8075-85. doi: 10.1016/j.biomaterials.2013.07.030. Epub 2013 Jul 25.

[96] Jacobs JJ, Gilbert JL, Urban RM. **Corrosion of metal orthopaedic implants.** *J Bone Jt Surg Am* 1998;80:268e82.

[97] Pan J, Liao H, Leygraf C, Thierry D, Li J. **Variation of oxide films on titanium induced by osteoblast-like cell culture and the influence of an H_2O_2 pretreatment***. J Biomed Mater Res* 1998;40:244e56.

[98] Peters K, Unger RE, Gatti AM, Sabbioni E, Tsaryk R, Kirkpatrick CJ.: **Metallic nanoparticles exhibit paradoxical effects on oxidative stress and pro-inflammatory response in endothelial cells in vitro.** *Int J Immunopathol Pharmacol*. 2007 Oct-Dec;20(4):685-95.

[99] Tsaryk R, Peters K, Barth S, Unger RE, Scharnweber D, Kirkpatrick CJ.: **The role of oxidative stress in pro-inflammatory activation of human endothelial cells on Ti6Al4V alloy.** *Biomaterials.* 2013 Nov;34(33):8075-85. doi: 10.1016/j.biomaterials.2013.07.030. Epub 2013 Jul 25.

[100] Amstutz HC, Campbell P, Kossovsky N, Clarke IC.: **Mechanism and clinical significance of wear debris-induced osteolysis.** *Clin Orthop Relat Res.* 1992 Mar;(276):7-18.

[101] Nich C, Takakubo Y, Pajarinen J, Ainola M, Salem A, Sillat T, Rao AJ, Raska M, Tamaki Y, Takagi M, Konttinen YT, Goodman SB, Gallo J.: **Macrophages-Key cells in the response to wear debris from joint replacements**. *J Biomed Mater Res A.* 2013 Oct;101(10):3033-45.

[102] Nich C, Takakubo Y, Pajarinen J, Ainola M, Salem A, Sillat T, Rao AJ, Raska M, Tamaki Y, Takagi M, Konttinen YT, Goodman SB, Gallo J.: **Macrophages-Key cells in the response to wear debris from joint replacements**. *J Biomed Mater Res A.* 2013 Oct;101(10):3033-45.

[103] Shardlow DL, Stone MH, Ingham E, Fisher J.: **Cement particles containing radio-opacifiers stimulate pro-osteolytic cytokine production from a human monocytic cell line.** *J Bone Joint Surg Br.* 2003 Aug;85(6):900-5.

[104] Babiak I: **Wear of acrylic cement (methylene-polymethacrylate) can manifest as extraosseous cement granuloma or false aneurysm of the popliteal artery after total knee arthroplasty**. *J Long Term Eff Med Implants.* 2014;24(2-3):139-45.

[105] Goodman SB, Magee FP, Fornasier VL.: **Radiological and histological study of aseptic loosening using a cemented tibial hemiarthroplasty in the rabbit knee.** *Biomaterials.* 1993 Jun;14(7):522-8.

[106] Aspenberg P, van der Vis H**.: Fluid pressure may cause periprosthetic osteolysis. Particles are not the only thing**. *Acta Orthop Scand.* 1998 Feb;69(1):1-4.

[107] Fahlgren A, Bostrom MP, Yang X, Johansson L, Edlund U, Agholme F, Aspenberg P.: **Fluid pressure and flow as a cause of bone resorption**. *Acta Orthop.* 2010 Aug;81(4):508-16.
[108] Fahlgren A, Bostrom MP, Yang X, Johansson L, Edlund U, Agholme F, Aspenberg P.: **Fluid pressure and flow as a cause of bone resorption**. *Acta Orthop.* 2010 Aug;81(4):508-16.
[109] Fahlgren A, Bostrom MP, Yang X, Johansson L, Edlund U, Agholme F, Aspenberg P.: **Fluid pressure and flow as a cause of bone resorption**. *Acta Orthop.* 2010 Aug;81(4):508-16.
[110] Fahlgren A, Bostrom MP, Yang X, Johansson L, Edlund U, Agholme F, Aspenberg P.: **Fluid pressure and flow as a cause of bone resorption**. *Acta Orthop.* 2010 Aug;81(4):508-16.
[111] Fahlgren A, Bostrom MP, Yang X, Johansson L, Edlund U, Agholme F, Aspenberg P.: **Fluid pressure and flow as a cause of bone resorption**. *Acta Orthop.* 2010 Aug;81(4):508-16.
[112] Fahlgren A, Bostrom MP, Yang X, Johansson L, Edlund U, Agholme F, Aspenberg P.: **Fluid pressure and flow as a cause of bone resorption**. *Acta Orthop.* 2010 Aug;81(4):508-16.
[113] Jaroma A, Soininvaara T, Kröger H.: **Periprosthetic tibial bone mineral density changes after total knee arthroplasty**. *Acta Orthop.* 2016 Jun;87(3):268-73. doi: 10.3109/17453674.2016.1173982. Epub 2016 Apr 27.
[114] Werner FW, Ayers DC, Maletsky LP, Rullkoetter PJ.: **The effect of valgus/varus malalignment on load distribution in total knee replacements**. *J Biomech.* 2005 Feb;38(2):349-55.
[115] Hurwitz D E, Sumner D R, Andriacchi T P, Sugar D A. **Dynamic knee loads during gait predict proximal tibial bone distribution**. *J Biomech* 1998; 31 (5): 423-30.
[116] Baliunas A J, Hurwitz D E, Ryals A B, Karrar A, Case J P, Block J A, Andriacchi T P.: **Increased knee joint loads during walking are present in subjects with knee osteoarthritis.** *Osteoarthritis Cartilage* 2002; 10 (7): 573-9.
[117] Mündermann A, Dyrby CO, D'Lima DD, Colwell CW Jr, Andriacchi TP.: **In vivo knee loading characteristics during activities of daily living as measured by an instrumented total knee replacement.** *J Orthop Res.* 2008 Sep;26(9):1167-72.
[118] Kutzner I, Bender A, Dymke J, Duda G, von Roth P, Bergmann G.: **Mediolateral force distribution at the knee joint shifts across activities and is driven by tibiofemoral alignment**. *Bone Joint J.* 2017 Jun;99-B(6):779-787.
[119] Baliunas A J, Hurwitz D E, Ryals A B, Karrar A, Case J P, Block J A, Andriacchi T P.: **Increased knee joint loads during walking are present in subjects with knee osteoarthritis.** *Osteoarthritis Cartilage* 2002; 10 (7): 573-9.
[120] Jaroma A, Soininvaara T, Kröger H.: **Periprosthetic tibial bone mineral density changes after total knee arthroplasty**. *Acta Orthop.* 2016 Jun;87(3):268-73. doi: 10.3109/17453674.2016.1173982. Epub 2016 Apr 27.
[121] Innocenti B, Truyens E, Labey L, Wong P, Victor J, Bellemans J.: **Can medio-lateral baseplate position and load sharing induce asymptomatic local bone resorption of the proximal tibia? A finite element study**. *J Orthop Surg Res.* 2009 Jul 17;4:26.
[122] Innocenti B, Truyens E, Labey L, Wong P, Victor J, Bellemans J.: **Can medio-lateral baseplate position and load sharing induce asymptomatic local bone resorption of the proximal tibia? A finite element study**. *J Orthop Surg Res.* 2009 Jul 17;4:26.
[123] Mündermann A, Dyrby CO, D'Lima DD, Colwell CW Jr, Andriacchi TP.: **In vivo knee loading characteristics during activities of daily living as measured by an instrumented total knee replacement.** *J Orthop Res.* 2008 Sep;26(9):1167-72.
[124] Jaroma A, Soininvaara T, Kröger H.: **Periprosthetic tibial bone mineral density changes after total knee arthroplasty**. *Acta Orthop.* 2016 Jun;87(3):268-73. doi: 10.3109/17453674.2016.1173982. Epub 2016 Apr 27.

[125] Martin JR, Watts CD, Levy DL, Kim RH.**: Medial Tibial Stress Shielding: A Limitation of Cobalt Chromium Tibial Baseplate**s. *J Arthroplasty.* 2017 Feb;32(2):558-562.

[126] Martin JR, Watts CD, Levy DL, Miner TM, Springer BD, Kim RH.: T**ibial Tray Thickness Significantly Increases Medial Tibial Bone Resorption in Cobalt-Chromium Total Knee Arthroplasty Implants.***J Arthroplasty*. 2017 Jan;32(1):79-82.

[127] Martin JR, Watts CD, Levy DL, Miner TM, Springer BD, Kim RH.: T**ibial Tray Thickness Significantly Increases Medial Tibial Bone Resorption in Cobalt-Chromium Total Knee Arthroplasty Implants.***J Arthroplasty*. 2017 Jan;32(1):79-82.

[128] Jaroma A, Soininvaara T, Kröger H.: **Periprosthetic tibial bone mineral density changes after total knee arthroplasty**. *Acta Orthop.* 2016 Jun;87(3):268-73. doi: 10.3109/17453674.2016.1173982. Epub 2016 Apr 27.